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The Channel Tunnel.

THERE certainly is much reason for admiring the pertinacity displayed by the promoters of the Channel Tunnel scheme, and the businesslike promptitude with which they have decided to seize the present opportunity of bringing the project under the consideration of a Government assumed to hold less stringent views than their predecessors on the subject of National defence.

At the same time we cannot understand why any persons or any association of persons in this country should think it desirable to establish direct railway communication with the Continent. Probably the only exceptions are a few importers of foreign goods and the South Eastern and Chatham Railway Company, who would doubtless be pleased to accommodate additional traffic, but so far as we are aware have not exhibited any disposition to take an active part in the speculative enterprise of constructing the proposed tunnel.

Matters stand upon quite a different footing in France and on the Continent generally, because Great Britain is an important market for foreign products, the export of which might be increased to some extent if means of avoiding transhipment were provided. Moreover, nations whose security is assured by powerful military organisations have no reason for objecting to a scheme whose

effect would be to abolish the natural frontier now separating them from a peaceful country having a few troops but no regular army worthy of the name in the modern acceptation of the term.

Apart from interested parties who are willing to use the tunnel if built with other people's money, and of those who are anxious to build it with other people's money, we have no evidence of any general demand for such a work, and no arguments advanced so far in its favour serve to commend the project to the investing public.

One of the most powerful arguments against the undertaking from the financial standpoint is the doubt still existing as to the possibility of constructing the tunnel.

In connection with this point we may appropriately refer the reader to some remarks in a pamphlet written by M. Albert Sartiaux, general manager of the Northern Railway of France, and an ardent supporter of the scheme. Referring to constructional difficulties the writer is obliged to admit that "the necessity of keeping to strata where infiltration is not to be feared renders it a somewhat delicate problem," and a little further on he says:—"The first and certainly the most important of all problems would be the necessity of working in the impermeable stratum safe from any infiltration of sea water. It can safely be said that the whole question of the successful completion of the tunnel lies in this possibility, the rest being accessory."

M. Sartiaux is unable to bring forward any conclusive evidence as to the existence of a continuous impermeable stratum between the two countries. He quotes the results of soundings which confirm the supposition that the straits were hollowed out at a comparatively recent period by erosion and not by subsidence and rupture. Beyond this he is only able to point to the similarity of the strata on each side of the Channel as demonstrated by experimental works, and to the extremely guarded opinions of French and English geologists. For example, M. Dollfus is quoted as having stated before the Geological Society of France, in November last, that wherever soundings had been made the lower chalk was identical in structure and thickness, and consequently that "if it is possible to go through this bed for the whole way without being obliged to pass through another it can certainly be reckoned that the tunnel can be bored without risk of surprises."

It is a point particularly worth remembering that no one is in a position to answer the question here raised. Even if we dismiss the hypothesis held by some authorities to the effect that the formation of the Channel was due in part to dislocation of underlying strata, the existence of inclined surfaces of infiltration cannot be overlooked. One important plane of the kind has been located between the Varne Bank and the French coast, and it is not improbable that others exist. Therefore unless the quantity of water gaining admission to the proposed works should prove to be within the capacity of modern pumping plant it might become necessary to abandon the undertaking after the expenditure of several millions.

Only a trial heading along the entire length of the proposed route can establish the hypothesis which is so cheerfully accepted as a fundamental fact by the promoters of the Channel Tunnel Bill.

Consequently, the enterprise foreshadowed in the measure before Parliament is of highly speculative character, and putting the position plainly the public will not be invited to subscribe money for constructing the tunnel but rather for the purpose of finding out whether the tunnel can be constructed—a very different thing.

Assuming the absence of geological obstacles, there is nothing to prevent the realisation of the scheme as set forth in the Bill. In accordance with the recommendations of the Alison Committee, the Dover entrance to the tunnel is situated inland where it can be commanded by the Castle and western

batteries. Passing beneath the Shakespeare Cliff the tunnel descends* at a gradient of 1 in 54·8, and one of 1 in 194·3 until normal level is reached with the minimum depth of about 112 ft. below sea bottom. Beyond this point there is to be a gentle up gradient of 1 in 1,000 to the centre of the Channel, where junction will be made with the French portion of the tunnel. From end to end the tunnel will be about 30 miles long, 24 miles being under water.

The proposal is that the railway lines shall be carried in two circular tunnels, 36 ft. apart centre to centre, with intercommunication galleries at intervals. This arrangement certainly provides better than a single double-track tunnel for the safety of passengers, and should facilitate the operation of the ventilating apparatus, whose absolute efficiency is literally of vital importance.

The proposal is that work should be commenced by driving an iron lined trial heading of 11 ft. 6 in. diameter from shore to shore, with the primary object of determining the feasibility of the project, and the secondary object of providing a drainage conduit for the removal of water during and after construction of the railway tunnels.

Ventilation and drainage are problems that can be satisfactorily solved by the aid of modern air propelling and pumping machinery, as the case of the Simplon Tunnel sufficiently indicates. One very serious objection, however, is the steep gradient of 1 in 54·8, extending for a length of about 3 miles at the English end of the tunnel and approach. More severe gradients are to be found in the world, but only of short length. For instance, the approach to the Prince of Wales Pier, Dover, is steeper, but the length is less than 100 yards, and we feel sure that railway engineers will agree with the view that for regular main line traffic the gradient of 1 in 54·8 for a length of three miles is quite impracticable. The defect here indicated is one that could be rectified by increasing the length of the approach railway.

The difference of gauge between British and Continental railways is too slight to constitute any obstacle to the free interchange of rolling stock. Thus we see that supposing geological conditions to be favourable, there is nothing to prevent the construction of the tunnel, and no reason why it could not be constructed so as to be perfectly suitable for its intended purpose.

We have next to consider how far this project is consistent with the continued safety of the country from the naval and military standpoint.

The construction of a tunnel affording facilities for the importation of foreign troops cannot be regarded with favour by the Admiralty, for the Navy is our first line of defence, and it is highly undesirable that naval protection should be undermined by the establishment of a land entrance into the island. Similarly, from the military point of view, it is out of the question to open a loophole for attack unless a great national army has first been established on modern Continental lines.

Even supposing the most efficient death-dealing machinery and appliances to be installed, the questions remaining to be answered are whether they could be maintained in a state of perfect efficiency, and whether they really would be used at the proper moment. We must not lose sight of the fact that these appliances could never be tested in position, and after years of exposure in a damp underground atmosphere it is morally certain that their efficiency would be a minus quantity. The responsibility of operating the destructive engines suggested by the promoters would be so tremendous that the man in charge might well hesitate to use them at the proper time, and so these safeguards would become of no avail even if in working order.

Again, we feel quite certain that the public would never consent to travel through a tunnel where they might be blown up, drowned, or asphyxiated, at an instant's notice as the result of false alarm or some blunder on the part of the attendant.

* *Cf.* the illustrations on pages 136 and 151

The Design and Construction of Mechanical Calculators.

IV.

By WILLIAM J. GOUDIE, B.Sc., A.M.I.Mech.E.

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THE instruments which have been dealt with are suitable for the continuous solution of only one equation of purely factorial type. It frequently happens, in various departments of engineering work, especially in that of machine design, that the engineer requires to handle a series of co-related expressions, two or more of which may contain common elements; and instead of a separate calculator for each equation it is usually possible to so arrange the various scales that one instrument may be made to serve for the solution of two or three of these. The mechanical embodiment of the separate equations in the instrument can be easily carried out by means of the foregoing design rules; but the accommodation of the requisite scales on the available scale lengths and circles usually entails the exercise of some ingenuity. Several illustrations of such "group" instruments will be given later.

The mechanical adaptation of the logarithmic principle can be further extended to certain types of expressions, which, although not purely factorial to begin with, can, by further application of the method of substitution, be converted into an equivalent factorial form, which enables them to be arranged for a continuous mechanical solution.

This class of quasi-factorial expression usually contains, as factors, bracketed quantities which are functions of some of the variable elements of the problem.

Note.—Previous articles appeared in Vol. xv., pp. 183, 258, 403.

By the method of substitution the scale of function values can be figured with the values of the elements which produce them, and hence any preliminary or final simplification of the expression can be avoided, and a direct mechanical solution can be obtained. The following expressions, which will be incorporated in the design of the typical calculators given later, will serve to illustrate this point.

The expression connecting the pitch P, revolutions R, speed S, and slip x of a screw propeller is written,

$$P = \frac{10133\,S}{R\,(100 - x)}$$

and contains the bracketed denominator factor, which is a function of the slip x. Instead of figuring the scale divisions of this factor with their actual values, the values of x can be substituted, and the scale can simply be reckoned as an equivalent "slip" scale. The familiar expression for the theoretical mean pressure of a steam engine is written,

$$P_m = P_1\left(\frac{1 + \log_e N}{N}\right) - P_b,$$

where P_1 and P_b are the initial and back pressures, and N is the nominal number of expansions.

The bracketed factor of the first term on the right is a function of N, and each scale value of this function can be figured with the N value which produces it. Further, by making P_b constant, say 4 lbs. per sq. in. for condensing engines, the equation may be written,

$$(P_m + 4) = P_1\left(\frac{1 + \log_e N}{N}\right),$$

and the $(Pm + 4)$ scale divisions can be figured with the corresponding Pm values.

Lewis's formula, $P = f\ b\ p\ y$, for the strength of wheel gearing, although of the purely factorial type, requires at least two tabular references before the solution can be proceeded with. In this case f is the safe stress and is some function of the circumferential velocity V of the wheel, and y is some function of the number of teeth n, when a tooth with standard angle of obliquity (15° or 20°) is fixed. By figuring the scale values of f and y with the corresponding V and n values, the instrument becomes automatic, as far as selection of values is concerned, and a direct mechanical solution is obtained by means of the substituted V and n scales.

Outside the purely factorial and quasi-factorial types of expression there are others, which, although not capable of embodiment to give a direct and continuous mechanical solution, may be so transformed as to enable the solution to be accomplished, with the addition of an initial or final simplification of some function of two or more of the variable elements.

The Board of Trade formula for the strength of marine engine shafting is a good example of this class of expression. It is written in the form,

$$S = \sqrt[3]{\frac{C\ P\ D^2}{f\left(2 + \frac{D^2}{d^2}\right)}}$$ Here $\frac{D^2}{d^2} = R$, the total cylinder ratio,

and the bracketed factor is therefore a function of this ratio, or a function of the two variable quantities, the high and low pressure cylinder diameters. If the value of R is known then the expression is of the same type as the first one relating to the propeller; but D and d may have any value whatever, so that the preliminary estimation of R and $(2 + R)$ becomes necessary before the continuous solution for S can be carried through. Other cases of a similar character might be cited, but these will probably be sufficient to indicate the general lines along which the designer should work, where the expression to be dealt with is not a purely factorial one.

There is, of course, a limit to the application of such methods. If the use of an instrument embodying a non-factorial expression, involves more time and trouble in arriving at the desired result than a plain arithmetical solution would, then the primary function of such an instrument is not fulfilled, and its construction represents so much waste of time and energy. The exercise of a little common sense will, as a rule, show the designer whether in any given case it is worth his while to construct a calculator to handle such an expression.

The Construction of the Straight Slide Calculator.—When the complete scale arrangement for any calculator has been settled, the next consideration of the designer is the kind of frame or stock and slides, whose construction will entail the least amount of labour, and which will be sufficiently strong to stand the wear and tear of every day use. In the majority of cases the home made article is constructed of wood. The most easily constructed arrangement consists of two strips for the fixed scales held apart by light brass strips, or distance pieces, riveted or otherwise fastened at their ends. Each strip is either tongued or grooved to take a corresponding groove or tongue on the adjacent slide. The two slides (for as already pointed out, the double-slide instrument is sufficient for nearly all practical purposes) are usually tongued and grooved at their traversing edges. End views of this design are shown in Figs. 14 and 15 The fixed strips should be made at least $\frac{5}{8}$ in. wide, and each slide $\frac{7}{8}$ in. wide, so that the necessary figuring and printing can be got on to the rule without undue crowding. The slides should project from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. beyond the brass strips at each end, so that they can be easily gripped with the fingers.

The stock or fixed part may, however, be made in one piece, and a wide groove cut along it to take the slide or slides, as in the case of the ordinary machine-cut slide rule. With this solid

FIG. 14.

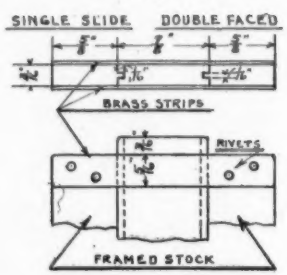


FIG. 15

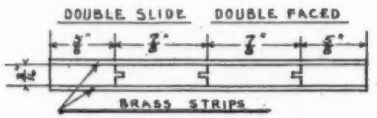


FIG 16.

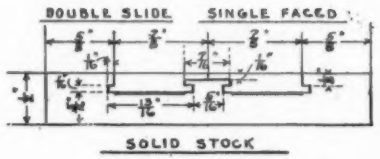


FIG 18.

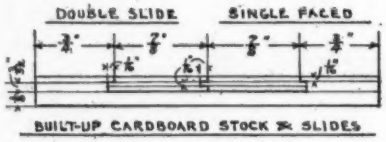


FIG. 17.

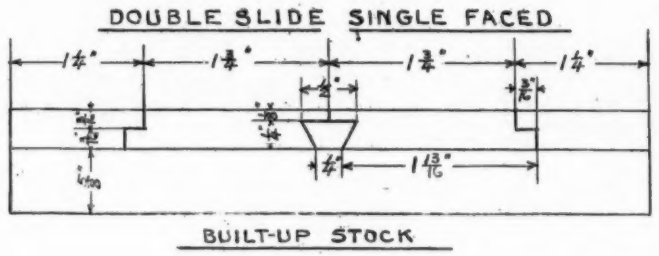


FIG. 19.

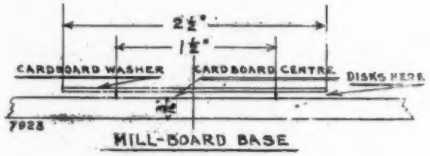


FIG 20

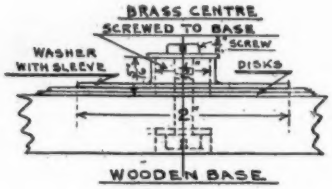
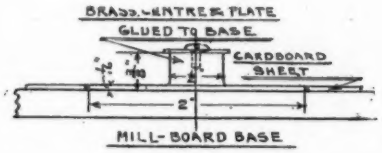


FIG. 21.



type a central grooved ridge can be provided in the case of the double slide instrument, in which each slide can work independently of the other. The sticking and simultaneous movement of the two slides, which often occurs with the other type is thus obviated, and when working this rule there is no interference or accidental displacement during the setting of the slides. An end view of one of these solid-stock double slide rules, cut to the writer's design by a firm of slide rule manufacturers, is shown in Fig. 16. It is made of boxwood. The slide edges at the centre are a close fit, yet each slide can be moved quite independently of its neighbour. The faces of the stock and slides are planed true and the scales can be drawn directly on to the wood. Wherever possible, this direct transference should be adopted, in preference to the method of drawing down the arrangement on paper or bristol board, and then mounting and cutting the card. Unless this is done with considerable care and skill, the rule may be spoiled and much patient labour wasted. As far as the writer is aware, specially cut rules of this class can only be obtained in quantity, so that for the majority of constructors the price is consequently prohibitive. Those who are sufficiently expert at the handling of woodworking tools should not, however, have much difficulty in "building up" a rule of this type. It must be constructed of thoroughly seasoned wood, as it is liable to be affected by atmospheric changes, which cause it to cap, and partly jamb the slides, thus rendering the instrument less easy to manipulate. The rules of operation can, if desired, be written or mounted on the back of the stock.

The first design mentioned has an advantage over this type in being double faced, and may therefore be used as a double calculator. Any rules of operation have then to be written on a separate card or slip, which, however, is apt to go astray just at the time it is required. The long type of calculator, whose length runs into several feet, is not to be recommended on account of its clumsiness. If, for any particular reason, any reader may desire to construct such a rule, the following details of one, designed by the writer some years ago to illustrate a lecture, may be of service. This instrument is 3 ft. 6 in. long and 6 in. wide. It has a teak back, $\frac{5}{8}$ in. thick, to which are fixed two strips of pine, $1\frac{1}{4}$ in. wide by $\frac{3}{8}$ in. thick, by means of screws driven in from the back. Each of the two slides is $1\frac{3}{4}$ in. wide by $\frac{3}{8}$ in. thick. A dovetail ridge of teak is screwed down along the centre of the back, and acts as a guide at the centre for the two slides. An end view of the rule is shown in Fig. 17.

The alternative to the wooden instrument is one built up of cardboard strips. The construction of this rule is rather a tedious business, but it requires only such simple accessories as a steel straight-edge, a knife, a paste-pot and a letter-press. It should be made of the best quality of bristol board, and as each layer of card is placed in position, it should be well pressed in the letter-press. Thick mill-board may also be used for the back. For the average size of rule, from 10 in. to 12 in. long, this backing should be about $\frac{3}{16}$ in. thick, as this kind of instrument has a tendency to take a curve lengthwise, unless it is provided with a sufficiently stiff back. The fixed strips can be made up of two layers, the upper overlapping the lower one so as to form a groove for the projecting portion of the adjacent slide. Each slide can be made up of three strips, the upper and lower strip of one slide overlapping the centre strip at one side so as to form a groove, and the centre strip of the other side overlapping the other two strips so as to fit into this groove. An end view of an actual cardboard rule of this class is shown in Fig. 18. At each end a small piece is cut out of the back board to enable the slides to be easily gripped with the fingers when they are "in" or the instrument is "closed." The cardboard rule is much lighter than the corresponding wooden one, but not so durable. Its wearing qualities are

increased by giving it a coat of white polish, thinned down by a large addition of methylated spirit. This puts a skin on the surface of the paper, and the rule can be cleaned by a damp sponge or cloth when it gets dirty through constant use.

The Construction of the Disk Calculator. When the circular type of instrument is adopted the work of construction is reduced to a minimum. It practically resolves itself into the construction and fixture of the centre about which the disks rotate. The disks can be cut out with a pair of scissors. The body of this instrument consists of a square base, which may be made either of wood or thick mill-board ; and the centre may be either of cardboard or metal, pasted or glued, or fixed by a screw to the base. The cardboard centre can easily be cut from a card by means of a stout needle filed to a chisel point and fixed in the pencil leg of a pair of compasses. This centre, and the corresponding holes in the disks, should be cut at one setting of the compasses. If any difficulty is found in cutting a card of sufficient thickness, the centre pieces from the base sheet and disks may be threaded on a needle and pasted together. The writer has tried this latter method and found it quite satisfactory. An extra centre piece should, however, be added to these cuttings so that the depth of the made-up centre may be just slightly in excess of the combined thickness of the base sheet and disks. The base sheet is threaded on this centre as well as the disks, to insure that its fixed scale circle will be concentric with the disk circles. The cardboard disk can be pasted down on the base, and the base sheet, when slipped over it, can be pasted down round the edges, or if the base is made of wood, fixed down by drawing pins at the corners. When the disks are placed in position on the centre they can be held down on it by means of a thick cardboard washer pasted on the top of the centre. Where the base is a wooden one this washer may be held down by means of a snap-headed screw nail and small washer, the nail being driven down through the centre into the wooden base. A suitable diameter for the centre is from 1 in. to 1½ in., and the covering washer may be made from one and a-half to twice the diameter of the centre. The cardboard centre and washer of a small disk instrument, constructed by the writer, is shown in Fig. 19. The lower disk is 6¾ in. dia. and the mill-board base is 8 in. × 8 in. × $\frac{5}{16}$ in. The centre is made up of the disk and base sheet cuttings plus an extra thickness, and the cardboard washer is pasted on the top of it. A round-headed paperfastener should be fixed in each disk, to enable it to be easily rotated. The projecting head serves as a knob, which can be caught by the tips of the fingers.

The metal centre can be made of brass, and need not be any larger than ½ in. dia. The holes in the disks and base sheet, in this instance, can be cut by means of a punch. This punch may consist of a piece of bronze turned to the diameter of the centre, with the end formed into a shallow cup, so as to give it a sharp cutting edge. By placing it on the disk or sheet and giving it a smart blow with a hammer a perfectly circular hole is produced. Where the base is made of wood the brass centre may be drilled through and tapped and fixed down on the board by means of a screwed pin and a washer fitting into a recessed hole in the back of the board, as shown in Fig. 20. A brass washer about 2 in. dia. may be used to keep the disks down in place. A small sleeve may be soldered to this to reach the top of the centre, which should be made from ¼ in. to ⅜ in. deep.

The combination can be held down permanently, by means of a small washer, the same diameter as the sleeve, and a pin screwed into the top of the centre. If when put together the washer presses too tightly on the disks the top of the sleeve can be filed until the requisite degree of freedom is obtained. When a mill-board base is employed, the centre should either be riveted or soldered to a thin brass flange, about $\frac{1}{16}$ in. thick and 2 in. diameter. The

centre can then be glued to the base by means of the flange, as shown in Fig. 21. A sheet of cardboard, the same thickness as the flange, can have a hole cut to take the flange, and can be pasted on the base, so as to bring the surface level up to that of the flange. The arrangement of brass centre and washer is superior to the cardboard one, but it is more troublesome and expensive to produce, if the constructor has not the necessary lathe and tools at his disposal. When the base is made of wood it should be from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. thick, and should be cut from a thoroughly seasoned board which will not cap unduly and bulge the base sheet. It is hardly possible to prevent capping altogether, and it is better to pin down the base sheet at the corners instead of pasting it, and to enlarge the pin holes sufficiently to give the board a little play. Where lightness is desired, in the case of a fairly large instrument, having say a fixed scale circle of about 12 ins. diameter, the base may be made of a compound wooden board, used by bookbinders. This consists of thin layers of wood placed with the grain of one layer at right angles to the grain of the other in order to counteract any warping tendency.

Mammoth Dredger for India.

By the operations of a large and very powerful suction and discharging dredger, named *Sandpiper*, recently launched from the works of Wm. Simons & Co., Ltd., Renfrew, the Calcutta Port Commissioners hope to remove the difficulties to navigation in the river Hooghly. This dredger, which is 235 ft. in length, has been specially designed for the unique character of the dredging to be done on the Hooghly, and has been constructed under the direction of Anthony G. Lyster, Esq. M.Inst.C.E., Engineer-in-Chief to the Mersey Docks and Harbour Board, Liverpool, assisted by Messrs. H. H. West & Son, Naval Architects, Liverpool.

The propelling and pumping engines are placed in two independent compartments, each engine-room being fitted with all the most modern auxiliaries. Propelling power is supplied from two sets of triple-expansion surface-condensing engines of the highest class embodying all the latest improvements in marine engine practice, including steam and hydraulic reversing gear, steam turning gear, independent circulating pumps, automatic feed pumps, feed heaters and filters, large evaporators for feed water make-up, and a complete outfit of auxiliary feed and bilge pumps. Steam is generated by four large single-ended horizontal multitubular boilers constructed to Lloyds and the Manchester Steam Users' Association standards for a working pressure of 180 lbs. per sq. in. These boilers are fitted in two stokeholds, communicating with each other. Steam ash hoists are fitted in each boiler compartment. The collective i.h.-p. of the engines is 4,500.

In view of the dredger being employed in a hot climate special study has been devoted to the ventilation of the engine and boiler spaces. The pumping outfit placed forward of the propelling engine in an independent engine-room consists of two sets of triple-expansion engines, with independent condensing plant and circulating pumps, complete with all modern fittings. The pump engines are coupled direct to two centrifugal sand pumps specially designed to raise and discharge 5000 tons of sand per hour at the low rate of 13 per cent. of sand to 87 per cent. of water, or, in other words,

SUCTION AND DISCHARGING DREDGER "SANDPIPER," CONSTRUCTED FOR THE CALCUTTA PORT COMMISSIONERS BY MESSRS. WM. SIMONS & CO., LTD., RENFREW.

the two dredging pumps together are capable of dealing with about 30,000 tons of sand and water per hour.

It was found from actual experiments that the maximum quantity of sand that fast flowing rivers can carry in suspense is 13 per cent., hence the reason for restricting the volume of sand to be discharged by the *Sandpiper* to this amount. The almost universal practice in carrying out dredging operations is to dispose of the material raised in one or other of the three following ways: (1) by discharging into the dredger's own hopper; (2) by discharging into hopper barges; (3) by discharging ashore for land reclamation. But at Calcutta it is proposed to discharge the material raised by the pumps directly into the river, the fast current of which, it is confidently expected, will convey the spoil to deep water before the sand has had time to settle. Each pump is connected to a separate suction pipe placed one on the port and one on the starboard side of the vessel. Each of the suction pipes is fitted at upper end with a very massive swivel bend, which serves as a trunnion, or hinge, upon which the pipe is free to move, either vertically or horizontally. The swivel bends are carried in slides on the ship's side, which permits of the suction pipes and swivel bends being brought completely inboard when required. Large sluice valves are fitted on the suction connections at ship's side. The suction end of each pipe is fitted with a specially designed nozzle to suit the character of the material to be dredged. A grid is fitted to the nozzles to exclude material which might choke or damage the pump. Each suction pipe is controlled by two independent derricks, one for each end,

which are both worked from the same steam winch placed on deck. These derrick winches are of most massive construction, each has four independent drums arranged to work separately or together as required, for lowering, hoisting, and derricking the pipes inboard. These winches form one of the most important details for the successful working of a dredger of such large dimensions, and are so arranged that one man is capable of manipulating the whole of the movements.

The discharge pipes from each sand pump are carried aft under deck on each side and united into one 51 ins. dia. pipe under the vessel's counter.

Special flexible connections are provided to meet the varying conditions between loaded and light draught of the dredger and floating pipe line. One of the outstanding features of the deck equipment of this dredger is the extensive and powerful installation of mooring winches to regulate the movements in the rapid currents of the river Hooghly. The winches are placed at bow and stern and consist of two duplicate sets, each having six independent drums and two ends for warping purposes, two of the drums arranged to work chains, and four of the drums are of very large diameter for working long lengths of heavy steel wire rope.

Each winch is driven by a vertical high pressure engine, the gearing throughout is of steel. A large workshop is fitted under deck so that all general repairs may be effected on board. The outfit of machine tools is very complete, and consists of lathe, shaping machine, radial drill, &c., also smith's forge, with mechanical fan, all driven by electric motors.

The hull and machinery is constructed to Lloyd's highest class. The deck is of steel sheathed with teak. Steam and hand steering gear is fitted, and a very complete installation of electric lighting is provided, including two search lights. Elaborate cabins are fitted up for the European officers and port officials, and provision is made for a large native crew. A refrigerating chamber is fitted up below deck for the preservation of provisions.

The floating pipe line in connection with the dredger consists of 600 ft. 51 ins. dia. steel piping carried on twelve pontoons. Each length of pipe is coupled by cast steel universal joints designed to give flexibility in any direction. A steam launch is provided for general service purpose, with special apparatus for lifting and laying moorings.

Modern Train-Speed Indicators.

II.

By CHAS. R. KING.

THE "Hasler" tachograph, as already shown, is modelled closely on the "Hausshaelter," although the principle of its working differs; for the barrel, 7, does not lift but, instead, the three nut segments, 27 (Figs. 22 and 25), mesh with the fine thread cut on the barrel, and their position—higher or lower upon the barrel as determined by the rotational speed of this latter—gives the positions required for the indication and registration of the speeds. The movements of the nut segments, 27, are communicated in succession to the bracelet, 15, encircling the barrel, 7. This bracelet forms part of the slide, 15, carrying the rack, 19. This rack engages with the toothed sector, 28, riveted to the indicator-hand of the dial, which hand points, every second, to the average rate of speed of the two seconds immediately preceding. The rack, 19, is likewise connected by the stem, 46, working in the slot of the plate, 43, to the punctuating needle, 45. The paper band, it will be noticed, passes behind the plate, 43. The movement for actuating the diagram punching mechanism, is as follows. The secondary spindle, 5, carries at its upper end the ratchet-disc, 10, (Figs. 23 and 24), and into the four notches of which the pawl, 43, is successively forced by the flat spring, 42, thus causing the needle to perforate the paper band. The paper is punched by the diagram needle immediately after the needle takes up its position. The needle-carrier is hinged so that, if the speed augments before it is clear of the paper again, there is no tendency to enlarge the perforated hole. These holes are punched in the speed-line, once in every 3 seconds. The paper is unrolled by clockwork at fixed rates of either 4, 6, or 8 mm. per minute, the length of the paper band required being, of course, twice as much for the last-named as for the first-named. The diagram band which we reproduce (see Fig. 21) travelled at 4 mm. per minute. It is here visible, that at speeds of above 40 km. per hour, it requires a magnifying glass to trace out the real speed-line. Consequently 8 mm. is to be preferred. The sample shows that the registration of speeds by needle pricks may be made so fine as to exceed the capacity of unaided eyesight, so, for every-day purposes, it is better to use more paper. In the "Hasler" the paper band is about 40 metres long; it has a width of 5 cm., and the height of the diagram may attain 4 cm.

The paper is paid out by the timing mechanism of the instrument. On the the spindle, 5, the small wheel, 11, (Fig. 23) transmits the motion to the paper driving barrels, 31 and 33 (Fig. 24), which draw the paper from the store spool, 37, on the right, and pass it to the box, 34, on the left, where it is rewound by a mechanism similar to that employed for rewinding the clockwork. The needle points on the edges of the driving rollers serve to grip the paper and at the same time to mark the intervals of one minute every 4, 6 or 8 mm. apart, according to the construction of the instrument.

The registration of the distance covered is effected by means of a row of holes perforated along the lower border of the paper band—similarly to the "Hausshaelter." The entire movement for this is seen in Fig. 23 by main driving-spindle 1, pinions 4 and 8, spindle 6, worm-gear 9 and 12. The edge-pinion, 12, revolves once in a half kilometer, or 500 metres,

as shown by the reproduced diagram opposite. This pinion carries a cam lifting a spring-lever 13, which in each revolution falls into the recess and causes the needle point attached to perforate the paper band from the back. The paper moves no faster as the speed increases, and the registrations in the time-line may occur so closely together that subsequent measurements on the diagram become somewhat difficult when the paper only has a speed of 4 mm. per minute on the "Hasler." When the driving wheels slip at full speed the closeness of the perforations increases the labour of tracing out the real speed line.

Otherwise, the frequency of speed registration by the "Hasler" tachograph places it next to centrifugal and differential machines for momentary speed indication.

The "Hasler" tachograph is sometimes fitted with a "Bourdon" gauge in connection with the train pipe of the compressed-air brake, and the air-pressures are registered upon the speed diagram—beneath the top line—by the action of the pneumatic spring in the "Bourdon" gauge. The punctuating needle-holder works in a slot just above the figure 43 (in Fig. 22) and the perforation of the paper occurs every three seconds, simultaneously with the punching of the speed line, but at a distance of 10 mm. removed from the speed diagram needle in order to avoid any contact of the two mechanisms. The scale for the air-pressures is 2 mm. per atmosphere, and the zero line for the registration is 12 mm. below the top kilometric line. The registrations show the power and frequency of the braking efforts and how and where the brake was employed, and the manner in which the air-pressure had been maintained. The utility of this addition cannot be questioned when we call to mind the Grantham disaster and the real ignorance of everyone as to the speed of the wrecked train and the action of the brake—all of which would have been revealed in detail by the automatic records of the "Hasler" tachograph.

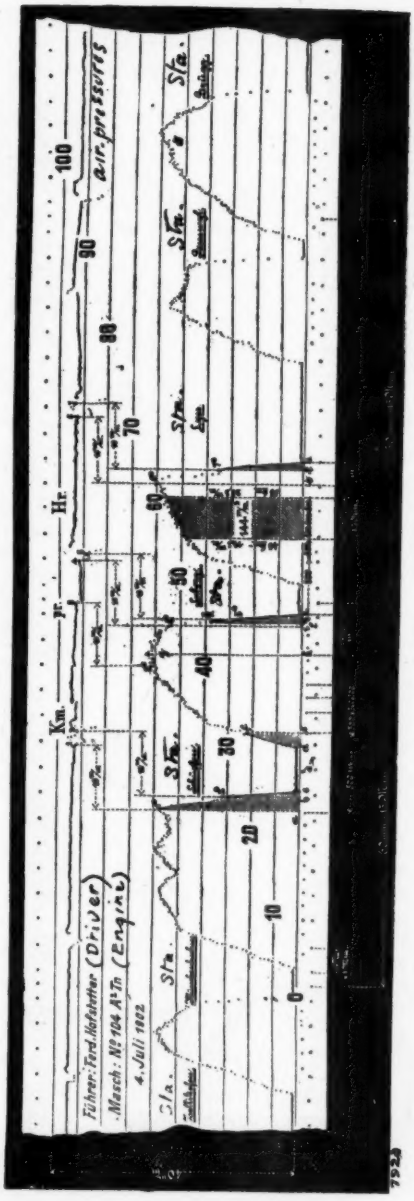


FIG 21.—A "HASLER" SPEED DIAGRAM.

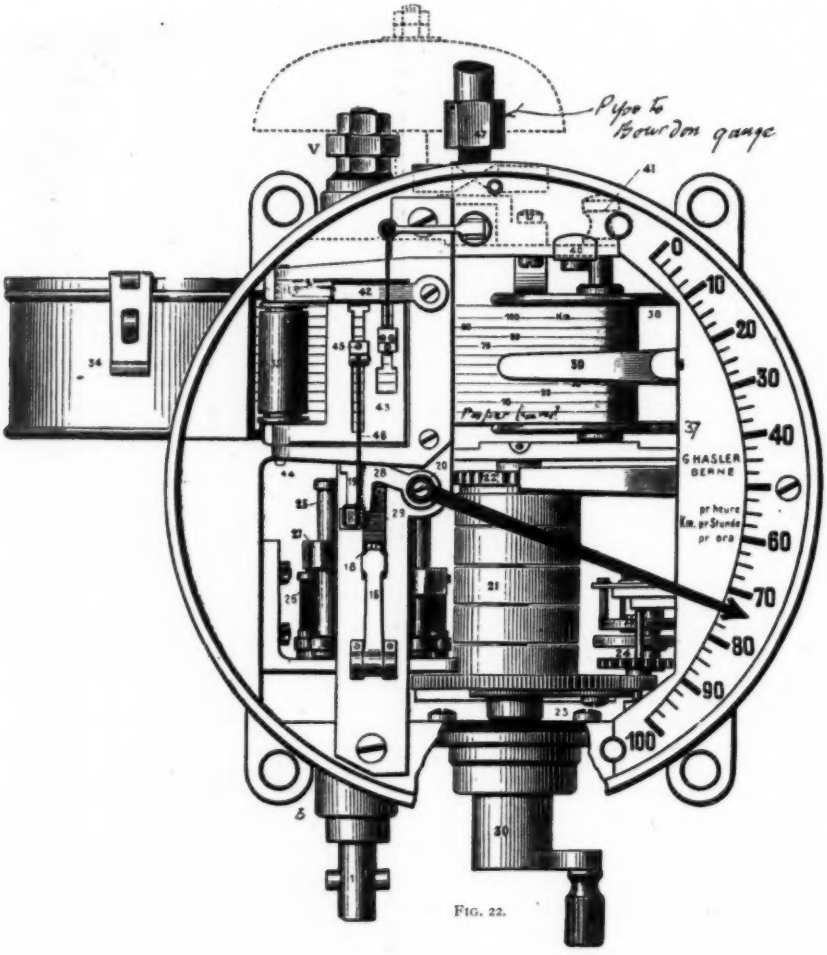


FIG. 22.

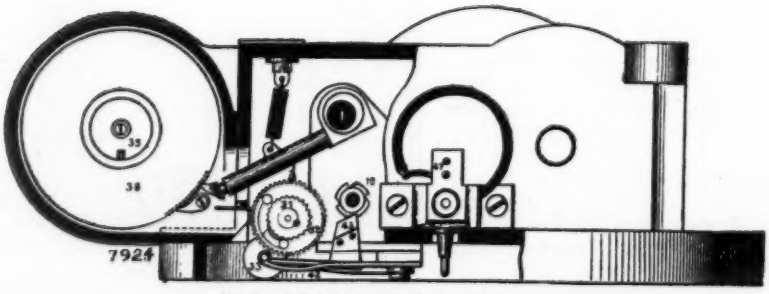


FIG. 24.—DETAILS OF THE "HASLER" SPEED INDICATOR.

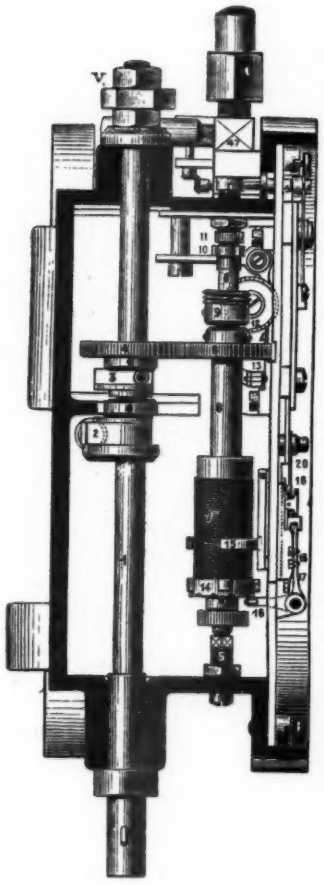


FIG. 23.

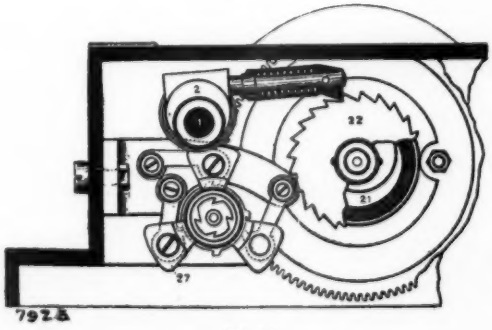


FIG. 25
DETAILS OF THE "HASLER" SPEED INDICATOR.

The "Flaman" tachograph (indicator and recorder) differs in principle from the other well known and excellent instruments. As already explained, the "Flaman" diagram differs from all other diagrams in giving the speed-line in a series of "steps" formed of ordinates and abscissæ — the ordinates representing speed and traced every 4·8 seconds or twelve and a half times per minute, while the intervals, representing any distance run without perceptible change in the speed, between two consecutive ordinates, are recorded by abscissæ. Thus if the latter correspond unvaryingly with any one of the longitudinal divisions (which, on the paper bands, represent the scale of speed in the proportion of 10 kilometres) then the straight line thus traced shows that the speed has not varied to the extent of one kilometre per hour.

It is sometimes urged that a needle prick is much finer than pencil or pen inscriptions, which are liable to become thick from wear. This is certainly visible in diagrams of the "Amsler" differential machine, but the difficulty is completely overcome by the fine paper and metal styles of the "Flaman" instrument.

To determine the rate of speed indicated at any given point on the line by the "Flaman" tachograph, it suffices to measure from the last stopping place or slack the length of paper corresponding to the precise distance covered and there erect a perpendicular or ordinate at the point so located. In a distance of rather over 100 miles, run without a stop, the amount of error does not exceed 200 yards. As in all systems of tachographs based upon the turning speed of driving wheels, frequent slipping

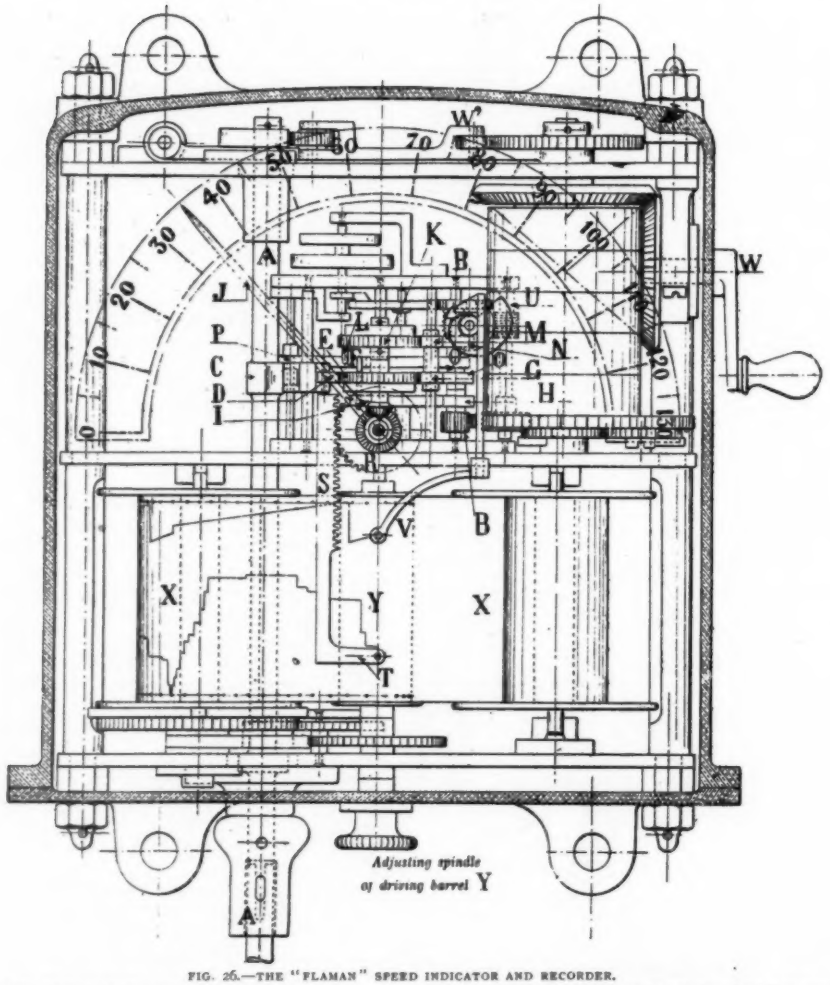


FIG. 26.—THE "FLAMAN" SPEED INDICATOR AND RECORDER.

A Main driving spindle of tachograph.
B Escapement shaft of clockwork.
C Driving cam for pawl.
D Driving pawl of ratchet wheel measuring speeds.
E Ratchet wheel measuring speeds.
F Stud on wheel E.
Z Fixed stop determining position of ratchet wheel at rest against the stud F.
G Stop-pawl of ratchet E.
H Cam to ungear the pawl D of the ratchet E at end of periods of speed-measure.
I Lever actuated by cam H to ungear the pawl D.
J Indicator hand of tachometer.
K Ratchet wheel transmitting to hand J the angular displacement of ratchet E.
L Stud on lower face of ratchet K serving to determine its angular position against the stud F of wheel E.
M Stop pawl of ratchet-wheel K.
N Cam actuating stop pawl M of ratchet K.
O Cam actuating stop pawl C. of ratchet E.
P Lever for gearing the pawl D with the wheel E at commencement of each period of time.
Q Cam actuating lever P.
R Toothed sector solid with hand J.
S Race transforming circular movement of speed hand into a vertical motion of which the ordinates are proportional to speeds.
T Speed-recording style.
U Spiral cam actuated by clockwork for registering the times.
V Time-recording style actuated by cam U.
X Paper band for receiving speeds, times, distances and stop duration
Y Driving barrel for paper band, the needle points of which perforate the paper at intervals corresponding to 1 kilometre.
W Hand-key for winding up clock.
W Automatic clock winder operated by the movement of the locomotive.

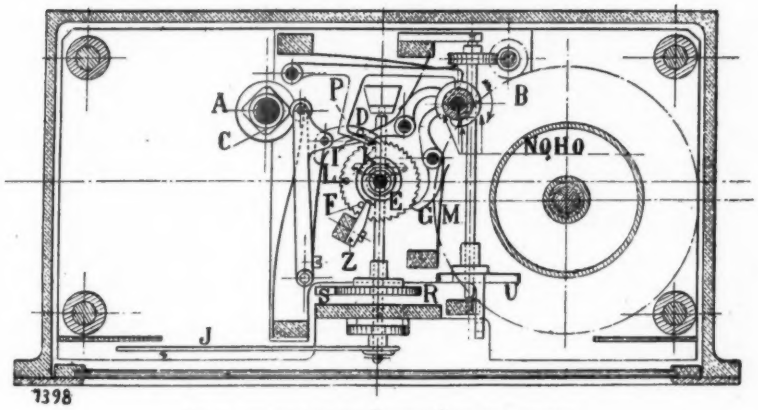


FIG. 27.—DETAILS OF THE "FLAMAN" SPEED INDICATOR.

of the drivers is liable to render this operation of locating the speed at a given point less easy and less certain. Hence the "Flaman" tachograph, whatever be the peculiar conditions of running, is still superior to others for the determination of the speed at a given point. By this term of "given point" is meant a space of between 100 and 200 yds. This is about the smallest space in which it is possible to measure correctly the position of a train, at high speed, on diagrams having a scale of only 5 millms. per 1,000 metres, as the "Flaman." Before adopting this instrument the Eastern Railway of France subjected it to an elaborate series of comparative tests.

In the comparative tests of the "Hausshaelter" and "Flaman" tachographs, the "Flaman" instrument was mounted side by side with the ordinary tachograph until then employed, and both were driven from the same speed-transmission shaft run from the crank pin of the driving wheels. After a series of exhaustive trials in various train services the superiority of the "Flaman" indicator decided the chief engineer of the running department, Eastern Railways of France, to adopt it with certain alterations. Since that time (1890) the results obtained from the perfected "Flaman" instrument have been such that it is being applied to all the locomotives of the Eastern Railway of France, and has

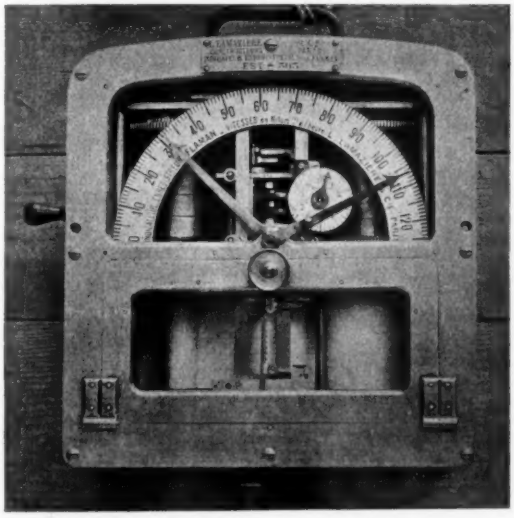


FIG. 28.—THE "FLAMAN" SPEED INDICATOR.

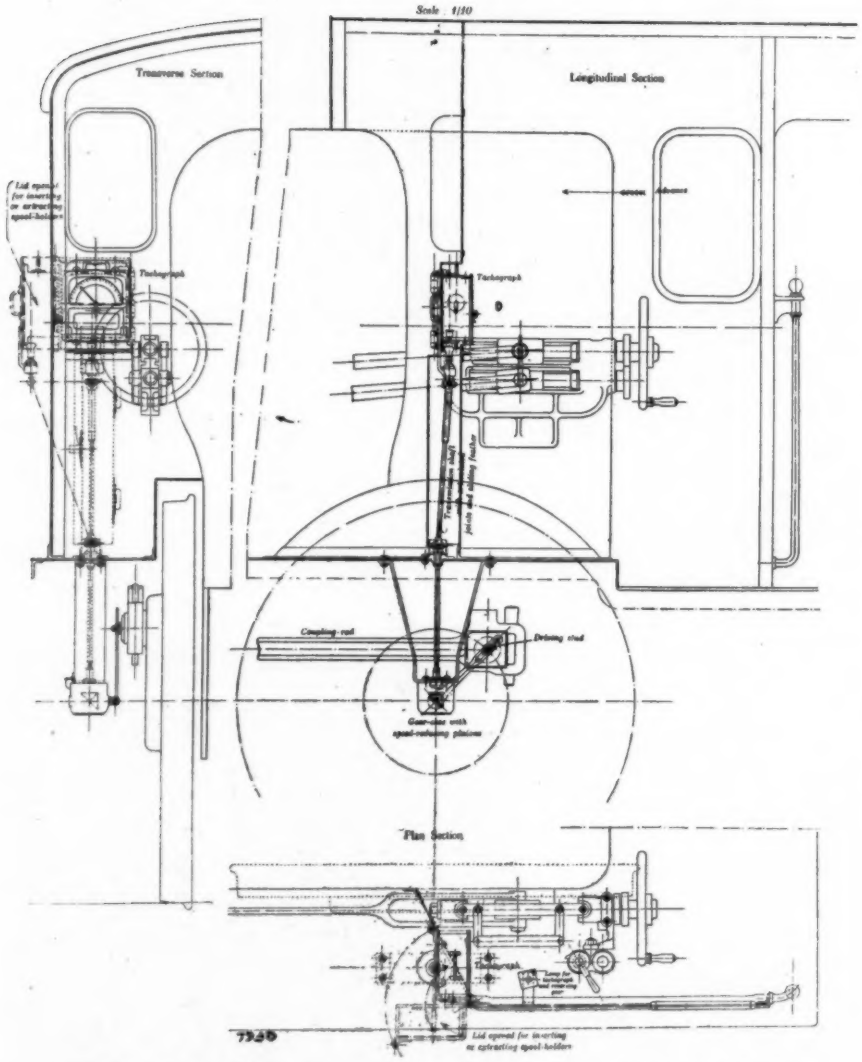


FIG. 29.—THE "FLAMAN" SPEED INDICATOR AS MOUNTED ON A LOCOMOTIVE TRANSMISSION BY SINGLE SET OF PINIONS.

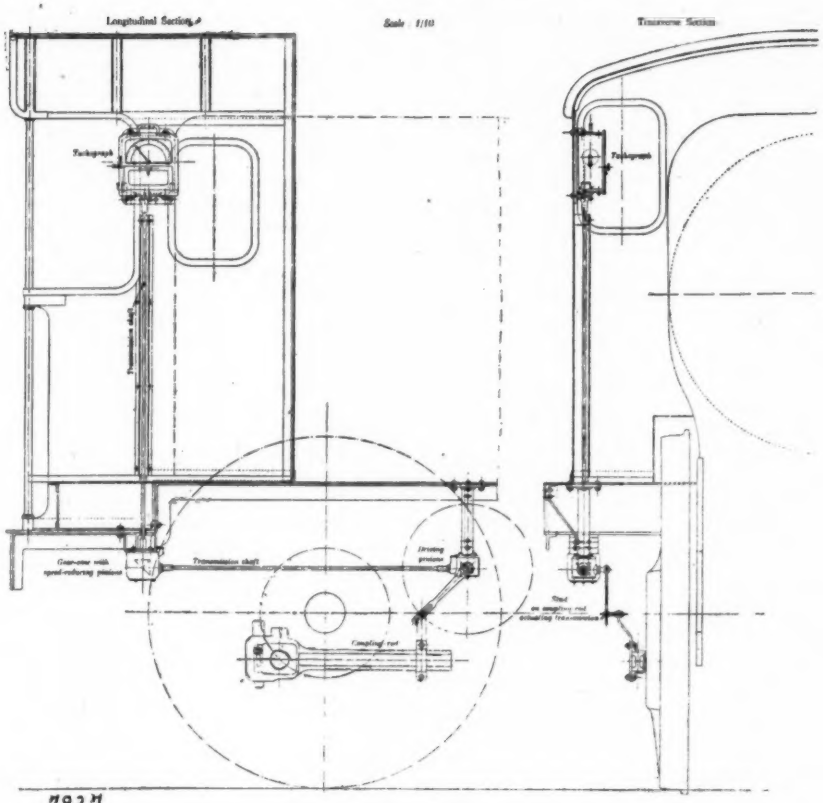


FIG. 30.—THE "FLAMAN" TACHOGRAPH, AS MOUNTED ON A LOCOMOTIVE. TRANSMISSION BY TWO SETS OF BEVEL-GEARS.

just been definitely adopted by all French railways. The indications and registrations effected by the apparatus are as follows:—

The distances are recorded by the paper band, upon which the speeds are marked, while unwinding at a rate of movement exactly proportionate to the distances covered on the rail. The paper travels from one spool to another in passing around a driving-barrel, which latter is provided at its upper and lower edges with needle-points that perforate the corresponding borders of the paper band at intervals of every five millimetres representing distances of one kilometre travelled between those intervals. To facilitate the counting of distances a double punctuation marks every 20 kilometres travelled. From this it is clear that it is precisely the *distance* which the locomotive is moved that gives the corresponding distances on the band, and not, as in other tachographs described, a clockwork movement that unwinds the paper band at the rate of so many millimetres of paper per minute.

The paper band in unrolling passes under the marking-style of the speed mechanism, which is actuated every

twelve and a half times per minute, that is once every 4·8 seconds, in giving the average speed of each 3·6 seconds preceding. Each of such records is inscribed in the form of an ordinate on the paper, the interval of repose between each successive marking being represented by the abscissæ. With no variation in the speed, either above or below that previously recorded, it will be obvious that the horizontal line would continue unwaveringly parallel with the ruled lines on the paper band.

In the usual diagrams reproduced here the scale of speeds is 0·4 millimetres per kilometre per hour=4 millimetres for each 10 kilometres per hour. The longitudinal ruling represents divisions of 10 kilometres up to 130 kilometres per hour.

The driver is notified continuously of the speed at which he is running by the dial-indicator in the cab. The speed is measured and then indicated and recorded simultaneously by a conjugation of the same mechanism. Briefly described, the measure of the speed is effected, in each of the successive intervals named, by means of a ratchet-wheel to which is imparted, during a period of time regulated by clockwork movement, an angular displacement, the extent of which is proportionate to the number of wheel revolutions during that time and consequently to the average lineal speed of the train's advance. The ratchet-wheel communicates its movements direct to the dial-hand of the indicator. The angular movement of the ratchet-wheel is shown on the indicator-dial by a corresponding angular position of the speed-hand.

A toothed sector, acting upon a rack, transforms the angular movement into a vertical one for the style-carrier, the movements of which mark the ordinates on the paper in due proportion to the speed indicated by the hand.

When the locomotive stops, the paper band ceases to move — contrary to ordinary indicators in which the band continues to unroll while the engine is stationary. In the absence of any horizontal movement during station stops the times are recorded on the band by a clockwork moving a style through a vertical path. The scale of this movement is 2 millimetres per minute. The time diagram, situated above the speed diagram, is divided into 10 divisions of 2 millimetres=2 centimetres total, and therefore records successive periods of time up to ten minutes. Arrived at the top of the diagram the style drops back to zero to reascend as before. This vertical movement is derived from a spiral cam which transforms a circular time-motion into a vertical one. When the engine is under way the vertical movement of the style is, on the moving paper band, reproduced in a sloping line which, with the subsequent return of the marker to zero at the end of each ten minutes, forms a series of zig-zags. In case of any appreciable drops or slackenings of the speed the sloping line becomes altered in form and permits of computations for the amount of time so lost from any cause.

The intervals of up to ten minutes in time are visible on a small round dial beneath the half-circular speed-dial. The time-dial is subdivided into forty divisions, each one corresponding to ¼ minute, otherwise fifteen seconds.

The diagrams traced furnish the momentary position of the engine at any point upon the line at a given moment; the time at which it reached various points; the duration of stops, of slacks, and of time lost in slipping, besides the rate of acceleration and periods of retardation, from coasting and braking.

The distances measured by the driving wheels have always been found to correspond with approximate exactitude to the axial length of the railway track traversed. As the diagrams are always of a length proportionate to the distance covered on the rail, it is possible to reconstitute exactly upon the diagram all the notable points in a run by taking for basis the distance separating the departure and arrival points, of which the mileage positions are known and which, moreover, are accurately indicated in the diagram. This is the principal and special advantage of the

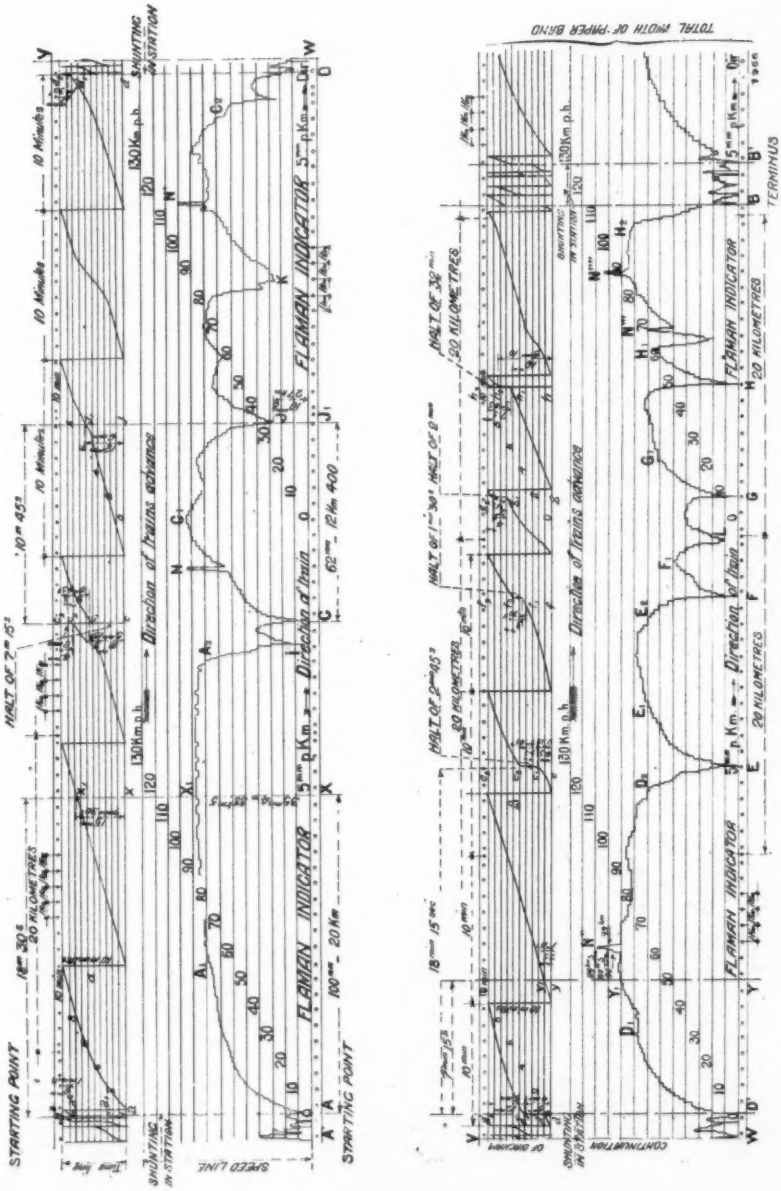


FIG. 31.—REPRODUCTION OF A "FLAMAN" INDICATOR DIAGRAM.

"Flaman" tachograph, and that which eliminates all chance of error arising from uncertainty as to the diameter of the tire at the tread. The actual rolling periphery of the tires may vary from minute to minute according to their lateral position upon the rail, or their diameter may decrease from wear, but the lesser or greater number of wheel revolutions thus made in traversing any given distance are transmitted mechanically to the feeding and space-dividing barrel of the paper band, so that the measure of the distances remains uninfluenced by such variations in the rolling circumference. The measure of distances and of speed has always been found satisfactory, whether the tachograph derived its movement from the driving wheels or from bearing wheels, exempt from all slipping movements as has been practised with a certain number of locomotives on the Northern Railway of France. The length of paper bands which can be rolled on the spool or carried in the spool-holders suffice for registering distances up to between 4,000 and 4,400 miles.

When the locomotive is at standstill and the clock has been completely wound up, this latter runs for about fifty minutes. After winding up, the winding-up key is taken off as the subsequent windings are then effected automatically by the engine while running. On the Eastern of France Railways only a difference of one second is permitted in ten minutes, and this, the maximum error at any time allowable, only amounts to twenty seconds in a journey of four hours.

The tachograph is applied to any type of machine by arranging the transmission gear so that the main driving spindle of the tachograph makes the same number of revolutions, this being effected simply by the choice of pinions suited to the diameter of the locomotive wheels. The mechanism of the tachograph is enclosed, hermetically-tight, in an iron box provided with a glazed front door for the placing or removal of spools and spool-holders. It is bolted to a wooden board in the cab, in any position from which the dial can be easily seen by the driver.

The annexed illustrations show:

Figs. 26 and 27. A front view of the tachograph, a plan section of the same, and a tabulated list of the principal working parts indicated by the reference letters on the drawings. This table permits of a complete understanding of the general details.

Fig. 29. The mounting of the tachograph with a transmission-gear composed of a single set of bevel pinions.

Fig. 30. The mounting of the tachograph with a double set of bevel pinions for the transmission.

Fig. 31. The reproduction of a diagram made by the apparatus, together with special reference letters not figuring on the ordinary bands for diagrams, but which are given here for purposes of reference only, as follows:

A, starting point.

B, terminal point.

C D E F G and *H*, intermediate stations at which the train stopped.

I J K L, slacks.

N N' N", slipping of driving wheels.

AA DD BB, shunting movements of the locomotive in stations at low speeds when going to train or returning to running depôt.

The interpretation of the diagram gives, among many other examples, the following readings:—A perpendicular XX^1 erected on the diagram 10 centimetres from its commencement represents a distance of 20 kilometres from the starting point. The speed line here has a height of 35·4 millimetres corresponding, therefore, with the scale employed, to a speed of 88·5 kilometres. On the time diagram above, the time elapsed is represented by the sum of the successive ordinates, a^2 to a^3, thence forward as far as x, x^1, the lengths of which are, as will be seen, $2+20+15=37$ millimetres, corresponding therefore, according to the scale employed, to 18 minutes 30 seconds.

From the second station *C* to the slack at *JJ*. the diagram measures 62 millimetres, corresponding therefore to

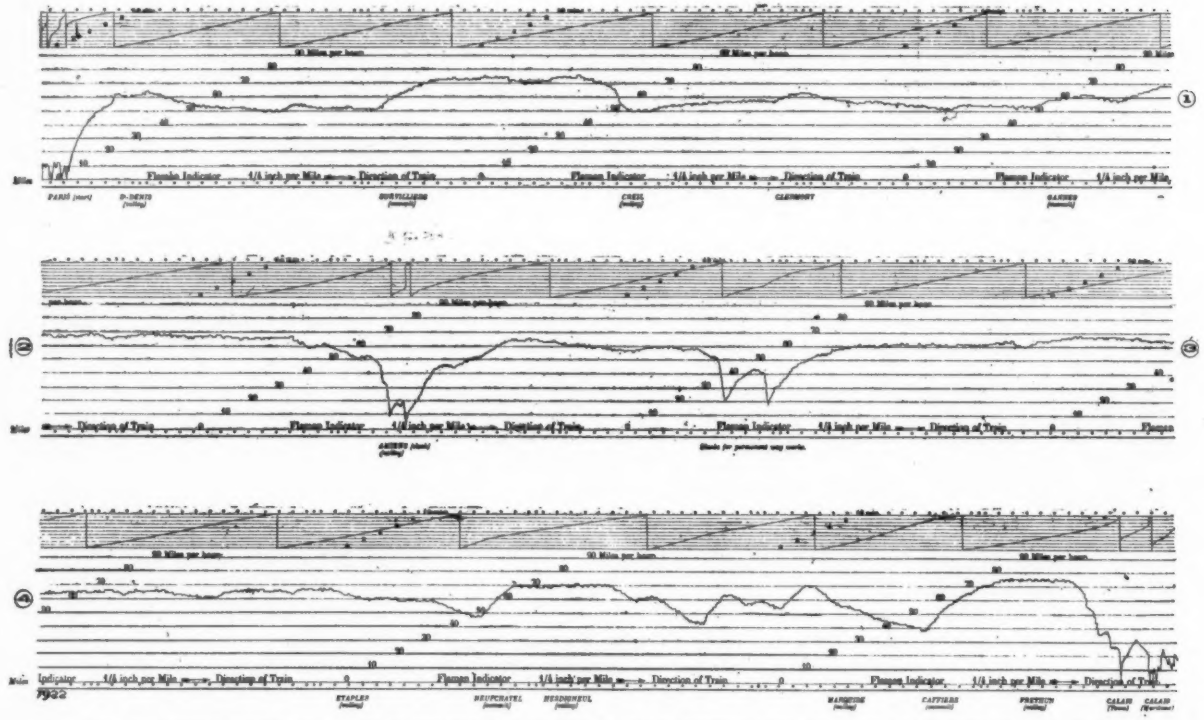


FIG. 32.—RUNNING DIAGRAM OF A TRAIN ON THE NORTHERN RAILWAY OF FRANCE BETWEEN PARIS AND CALAIS AS RECORDED BY THE "FLAMAN" SPEED INDICATOR.

Prepared at the suggestion of the author to show the running of "De Glehn" compounds in English measures.

a distance covered of 12·4 kilometres. The lowest drop in the speed line, during the slack, measures 10·8 millimetres from the datum line, corresponding therefore to a minimum speed of 27 kilometres per hour.

In the acceleration of the train starting from the station *D*, the time required to attain the speed of 90 kilometres per hour at Y^1 is given by the sum of the ordinates on the time diagram between *d* and *y*, these being 12+2.5=14·5 millimetres, representing therefore 7 minutes 15 seconds.

Slipping of the wheels can be analysed in all its phases by the measure of the ordinates composing the "steps" in the speed line at N^1 N^2 N^3 and N^4.

During all stops the time of immobility is given by the measure of the ordinates in the time line.

The reading of the results and easy solving of all these questions by means of the "Flaman" diagrams—questions which often occur in daily routine—show how yet other data may be deduced from the indications registered by this tachograph, independently of the momentary visual indications constantly furnished for the information of the driver.

Fig. 32 is a record made by one of the fast locomotives of the French Northern Railway.

Is a Duodecimal System Possible?

THE question of the Metric System is very much in the air at the present time; and some of the opponents of its adoption in this country have raised the objection that the Decimal System is inferior to the Duodecimal System. As there must be many who do not properly understand what the term "Duodecimal System" implies, a few explanatory remarks may not be out of place. It is fairly well understood, of course, that our present system of notation, or enumeration, has for its base the number ten. In this way a number such as fourteen is expressed by one ten and four units, or otherwise 14, the number thirty-six by three tens and six units, or otherwise 36; and so on. If, now, the number twelve be taken as the base of our system of enumeration, the number 14 will no longer denote one ten and four units, but one *twelve* and four units, that is, the present number sixteen. The number 36 would denote, not three tens and six units, but three *twelves* and six units, that is, the present number forty-two. Without finding further examples of this, it is at once clear that numbers above nine would no longer retain their old significance. We should not only have to learn their new meaning, it would be necessary, too, to forget the old. Now, since the number 10 would, in the new system, represent twelve, and 11 would represent thirteen, our first duty would be to find two new digits to represent the numbers ten and eleven. In mathematical work these are generally denoted by the letters T and E. Equipped with these two new digits, we can now venture upon a new multiplication table, which may be taken as a specimen of what would have to be learned by those who are enthusiastic enough to take up the study:—

4 × 1 = 4	4 × 7 = 24
4 × 2 = 8	4 × 8 = 28
4 × 3 = 10	4 × 9 = 30
4 × 4 = 14	4 × T = 34
4 × 5 = 18	4 × E = 38
4 × 6 = 20	4 × 10 = 40 (*i.e.*, our present forty-eight).

The prospect of having to learn new multiplication tables, and to become familiar with the new significance of numbers is assuredly not an alluring one. We should still, it is true, have seven days in the week, and but few would reconcile themselves to the idea that there are only ten months and 265 days in the year. On the other hand, the number thirteen would lose much of its fatal significance in the harmless guise of 11. Numbers that have hitherto been invariably connected with certain events would have to be ruthlessly torn from their environment.

So, too, in the question of time. We should have to be satisfied with 50 seconds to the minute, 50 minutes to the hour, and 20 hours would form a complete day. Once more, it may be asked: Are we prepared for such a change? We may wish that our primitive forefathers had adopted the number twelve as their base of notation; we may look with longing eyes at a system that is certainly superior to our own; but it is not for us. It is not too much, however, to hope that our people may have the enterprise to adapt our system of weights and measures to the decimal base, so that in weights and measures and in enumeration there may be one language that all can understand.

The Engineer's Library.

Modern Steam Turbines (Volume I.): **The "Schulz" Turbine.** By MAX DIETRICH. Edited by Arthur Liddell. (London: A. Owen & Co. and T. Fisher Unwin.) 73 pp., 43 illustrations. 5s. net.

This book is a translation from the German work, "Die Dampfturbine von Schulz." Schulz is engine works manager to Krupp's Shipbuilding Works at Kiel, and consequently has developed his turbine largely with a view to marine, and especially naval applications. The "Schulz" turbine is sometimes arranged on the "Rateau" or "Zoelly" principle, sometimes on the "Curtis" principle, sometimes on the "Parsons" or reaction principle, and sometimes—indeed generally—it is a combination of several types. In the reaction turbine, Schulz makes a great point of having so split up and arranged the expansion stages as to balance end thrust without the use of dummy balance pistons, such as are employed by Parsons. Schulz also makes a great point of controlling the admission ports to all stages of his impulse turbines, according to the load to be carried. Generally speaking, his arrangements seem to be distinctly complicated and unsatisfactory.

Schulz also makes a strong point of his method of varying the steam and mechanical connections of several turbines for marine work at variable speeds, and claims to be the original inventor of the method.

The book is all praise for Schulz and bitterness against Parsons. The descriptive matter is short and largely relates to patent specifications, whilst many of the illustrations are poor. It is to be hoped that succeeding volumes of this series will be better than the first.

Turbines. By W. H. STUART GARNETT, Barrister-at-Law. (London: George Bell & Sons.) 283 pp., 81 illustrations. 8s. 6d. net.

This book deals with both hydraulic and steam turbines. It has been written chiefly for those who desire a lucid description of the scientific principles underlying turbine construction, without the employment of mathematics or the formal style of a student's text book. The book, indeed, contains no mathematics, and will on that account be welcomed by those whose interest in turbines is of a general nature.

The first half of the book is devoted to hydraulic turbines. There is an interesting sketch of the history of hydraulic turbines, followed by a description of the main constructive features and the underlying principles of the chief types. There is also a chapter on erection and control. The discussion of the steam turbine proceeds along similar lines to that adopted in the first half of the book when dealing with hydraulic turbines. More space is devoted to the "Parsons" than to all the other turbines, and it is rather a pity that the author has not been a little more open in his acknowledgment of the undoubted defects as well as the good points of this and other turbines. The inferior reliability under service conditions is the main drawback to the adoption of steam turbines in all sizes above about 750 kilowatts, below which size, economy and first cost both favour the reciprocator. The book includes a chapter on marine turbines, and also discusses briefly turbo-blowers and pumps. The book is well written, and, with the exception of some of the half-tones, the illustrations are very clear.

The Marine Steam Turbine. Second Edition. By J. W. SOTHERN. (London: Whittaker & Co.) 163 pp. 6s net.

As the title indicates, this little book deals only with the marine steam turbine. Moreover, only the "Parsons" turbine is treated of, although the "Rateau," "Zoelly," "Schulz," "Curtis," and "De Laval" turbines have all been successfully applied to ship propulsion. The book does not pretend, however, to be a treatise on turbines, but is, as the author states in his preface, for those who wish to obtain practical information regarding the "Parsons" marine turbine. It fulfils this function very well, the illustrations being particularly good.

The author also gives a considerable quantity of useful data obtained from actual marine turbines, but is apt to generalise too much from particular examples. On turbine theory and, indeed, on physical science generally, Mr. Sothern is not too safe a guide. Thus, for instance, his method of calculating the clearance leakage over the blade tips is very unsatisfactory. The author gives copious extracts—almost the whole paper, in fact—from Mr. Speakman's 1905 paper on marine turbines, and would have done better if he had incorporated the substance in his own words along with the rest of the text.

The book has been divided into three sections. The first deals—rather unsatisfactorily—with turbine theory; the second gives excellent descriptions of marine turbine details and arrangements; and the third is a collection of data taken from practice.

The book will be found very useful to all who are looking for a practical account of the "Parsons" marine steam turbine.

The Theta-Phi Diagram, practically applied to Steam, Gas, Oil and Air Engines. By HENRY A. GOLDING. A.M.I.Mech.E., Works Manager, Messrs, James and Browne, Ltd. 1906. (Manchester: The Technical Publishing Co., Ltd.) 3s. net.

The first edition of this work appeared in 1898. In this new edition various corrections and additions have been made in the text. The contents of the volume are well indicated by the title, and those of our readers who have not seen this work, but have occasionally spent valuable time in hunting out from the Proceedings of the Institution of Civil Engineers, Mr. Macfarlane Gray's paper explaining his "$\theta\phi$ diagram" and its application to thermodynamical problems, or have sought long for some of the subsequent papers in which Mr. Gray's ideas have been further developed, will be glad to learn that they can have, in this readily accessible form, the substance of these papers. Exception might be taken to the author's definition of entropy as "the co-ordinate with temperature of energy"—a definition which would, we fear, disturb Mr. Swinburne; but we need not dwell on that here, as the author's main concern is with the practical uses of the $\theta\phi$ diagram, and his discussion should be helpful to the engineer. In his preface the author laments the lack of investigations on the specific heats of gaseous mixtures at high temperatures, such as are found in gas engines. This is very true, and the position is made still more unsatisfactory when we find the only available results rejected as untrustworthy in the recent report of the Committee of the Institution of Civil Engineers on the efficiency of internal combustion engines. Since that report was issued, however, this subject has been dealt with by Mr. Dugald Clerk in a most interesting manner in a paper read before the Royal Society on March 15, 1906 (see "Proc. Roy. Soc.," A., vol. 77, "on the Specific Heat of, Flow from, and other Phenomena of, the Working Fluid in the Cylinder of the Internal Combustion Engine").

A Text-Book of Practical Physics. By WILLIAM WATSON, A.R.C.S., D.Sc. (Lond.), F.R.S. 1906. (London: Longmans, Green & Co.) 9s.

Where laboratory classes in practical physics are moderately large, it is impossible for teachers or demonstrators to give personal supervision at all times to the work of each student, and for this reason it is a common practice to introduce the use of a text-book, by reference to which the student may be enabled to carry out his experiment when left to himself. Teachers also make use of such text-books in arranging their courses of instruction. Now the effect of this practice upon the students—whether it is to be good or evil—depends to a very large extent upon the text-book selected; for, unfortunately, some books of this class are constructed on wrong lines. Some authors have made their books simply catalogues of experiments, in which full instructions are given as to the sequence of operations to be performed by the student in each experiment, and the result is that a student may go through a large part of the course and show results in his note-book without really understanding the principles underlying his experiments, or knowing what to do, and how to do it, when asked to repeat a particular experiment for himself without assistance. We have borne this in mind when reading Dr. Watson's new volume, and it is a great pleasure to find in it a work to which no adverse criticism of the kind just outlined could be applied. The author has aimed at training the student to accuracy in all his measurements, and to a complete knowledge, not only of what he is doing, but also why that should be done, and the result is a book which may safely be put into the hands of students by their teachers. It would be hard to find a book giving a more careful analysis and discussion of the common sources of error in instruments, such as are ordinarily used in a physical laboratory, than that contained in these pages; and if students will pay attention to all the valuable instruction here given, and put it in practice in their laboratory work, they will understand at the end the true value of an experimental course, and will have acquired the habit of exactness, so valuable and necessary for success in science. On the other hand, we hope they will study the author's discussion at the beginning of his book, on the correct apportionment of the accuracy with which observations are made, as they will thereby learn how time and trouble may be uselessly spent in endeavouring to make measurements to a degree of exactness which is not justified.

The course of instruction given by Dr. Watson is intended for students who have already gone through an elementary course, and it provides ample material from which teachers may select. The volume has been most carefully prepared, and should be very useful.

The Practical Electrician's Pocket Book and Diary. 1907. (London: S. Rentell & Co., Ltd., 36, Maiden Lane.) Price 1s. net.

The Science Year Book. Diary, Directory and Scientific Summary. (London: King, Sell and Olding, Ltd., 27, Chancery Lane, W.C.) Price 5s. net.

Sanitary Engineering with respect to Water Supply and Sewage Disposal. By L. F. VERNON-HARCOURT, M.A., M.Inst.C.E. (London: Messrs. Longmans, Green & Co.) Price 14s. net.

Modern American Machine Tools. By C. H. BENJAMIN, M.A.Soc.M.E., with 134 illustrations. (London: Archibald Constable & Co., Ltd.) Price, 18s. net.

This volume forms a welcome addition to the literature of mechanical engineering, comprising as it does a handy compendium of machine tools now manufactured in the United States. Within the last two years many interesting developments in design have emanated from American builders, and to possess in a handy form descriptions of the design and construction of such machines, thus saving the trouble of referring to scattered articles, is an advantage which will be generally appreciated.

The book suffers somewhat, in that it is confined to those machines which find use in a general machine shop; for example, planing, turning, boring and drilling machinery, milling and grinding machines, and also machinery for shearing and punching metal for cutting screw threads. Several interesting models have, however, recently been developed in connection with the motor car industry, which it seems to us could have been included with advantage, as illustrating the manner in which the specific requirements of manufacture can be readily met by the machine tool designer. The consideration of special tools is also of the highest importance to the student in connection with the study of design, although the omission will not affect the value of the book to the actual machine user. The chapter on gear-cutting machines has not received such full treatment as the subject deserves, and we can trace no reference to the process of hobbing or to a hobbing machine. Again, the chapter on "Tendencies in Modern Design" is brief and incomplete, especially as, rightly or wrongly, a number of engineers have been looking upon American designs as being in advance, whatever their shortcomings may be in actual operation. In this connection it is interesting to note that the author admits that "up to the present our British cousins have made more use of the invention (high speed steel) than we have ourselves, and they know more of its possibilities. American manufacturers are now waking up to the importance of the new discovery."

Gold Mining Machinery: Its Selection, Arrangement and Installation, including particulars for the Preparation of Specifications and Estimates. By W. H. TINNEY. (London: Crosby Lockwood & Son, 7, Stationers' Hall Court, E.C.) Price, 12s. 6d. net.

This is essentially a practical work, embodying points arising out of a valuable experience relating to the principal features of gold mining machinery—sizes, capacities and speeds, and, equally important, the rules and formulæ governing its use. It is, perhaps, the most comprehensive and generally useful book on the subject that we have yet seen, and every manager and mine engineer cannot fail to find it capable of rendering him practical assistance. The scope of the work may be indicated by the chapters which are as follows:—motive power, engine erecting, boilers, chimney, fuel and feed, management of motive power, pumping machinery, winding machinery, air compressors, rock drills, crushing machinery, concentrating and gold extracting plant, transmission of power, transport, piping and joints, construction, tackle and tools, details for estimates, and a valuable appendix of miscellaneous data. The book is clearly printed and well illustrated, and cannot be too highly recommended.

Verbal Notes and Sketches for Marine Engineers. By T. W. SOTHERN, M.I.E.S. Fifth Edition. (London: Whittaker & Co., Paternoster Sq., E.C.) Price, 7s. 6d. net.

For the new edition of this well known and highly appreciated handbook, the matter has been rearranged and numerous additions made both to text and illustrations. Two new sections have also been added dealing with propeller design and marine oil motors, both of which are well done and render the book all the more valuable. There is only one thing lacking to render the book completely up-to-date, and that is a section on the marine steam turbine. This addition would perhaps have rendered the volume cumbersome, but would nevertheless, have proved welcome to those who do not wish to incur the expense of a separate treatise. A capital index completes a well-printed, illustrated and invaluable work of general reference.

The Law of Building, Engineering and Shipbuilding Contracts, and of the Duties and Liabilities of Engineers, Architects, Surveyors and Valuers. By ALFRED A. HUDSON. Two Vols. Third Edition. (London: Sweet & Maxwell, Ltd., 3, Chancery Lane.) Price, £2 12s. 6d. (*Vol. I. ready in January*).

Building Contracts, Building Leases and Building Statutes. By HIS HONOUR JUDGE EMDEN. Fourth Edition. By J. B. MATTHEWS and W. VALENTINE BALL, Barristers-at-Law. (London: Butterworth & Co., 11 and 12, Bell Yard, Temple Bar, W.C. 1907.)

During the ten years that have elapsed since the appearance of the previous edition much has transpired affecting the interests of building owners, builders and architects, which has been incorporated in the edition just published, without unduly increasing its bulk. As a work of reference the volume is, of course, indispensable to building contractors and constructional engineers, and the addition of a very complete index renders reference almost a pleasure. It may be mentioned that a number of cases not mentioned in any of the law reports are given in the appendix.

A Dynamical Method of determining experimentally the Specific Heat under Constant Pressure of Superheated Steam.

(Original Experiments.)

By SYDNEY B. BILBROUGH, B.A.

IT is necessary here to emphasise the advantages in practice accruing from the use of superheated steam and the wide application that it is now receiving; what is of more importance is that our knowledge concerning its physical properties is still vague and uncertain. This applies more particularly to the specific heat of superheated steam, our knowledge of which was, until a few years ago, represented by the results obtained by Regnault. Subsequent experiments have been carefully made by careful investigators, the results of which, however, cannot be said to be conclusive. The latest to enter the field of this department of research is Mr. Bilbrough, who recently communicated an account of his investigations to the Transvaal Institute of Mechanical Engineers and has privileged us to print the paper in the hope of promoting a full discussion thereon. In view of the importance of the subject readers are cordially invited to carefully peruse Mr. Bilbrough's paper and to contribute to such discussion. For details of recent investigations in this subject THE ENGINEERING REVIEW, Vol. XIV., pp. 101, 178, 246 may be consulted.—ED.

The specific heat at constant pressure of superheated steam was determined by M. Regnault about the year 1850, and the average of four experiments gave ·4805.

But the same reliance has not been since placed on this result as all his other wonderful experiments, partly on account of the difficulty attending the experiment, and partly because it has been generally believed to be a variable quantity, dependent both on the temperature and the pressure of the superheated steam, and therefore could not be represented by one figure.

This paper describes the practical carrying out of the experiments, dependent on a different principle to that employed by Regnault, also what values can be deducted from these results, and Tables XII. and XIII. give a complete set of all the values of K, the specific heat required, for all temperatures and for two sets of pressures, viz., atmospheric and at 150 lbs. per sq. in.

In this paper are given formulæ for the use of these values of K, to determine the total heat of superheated steam, and also for estimating the wetness of steam by means of the Peabody throttling calorimeter.

The two last sections are chiefly theoretical. The underlying principle is proved in the opening section, and the equations for the deductions are given.

The fact that the value of K is of real commercial importance, gives the subject an interest to all mechanical engineers, as it is they only who will make practical use of the results obtained.

But the principle involved is also of scientific interest, and many more deductions from these results may be obtained and speculated with, but they are not discussed here.

Now there are two values of K, its value at a certain degree of superheat, and its average value from saturation to that degree of superheat.

These two values are different, because at low degrees of superheat, *i.e.*, 1 or 2 degrees above the saturation point, the value of K increases enormously as the steam approaches saturation.

The largest value obtained for K is no less than thirty-three times its value at high degrees of superheat where it is a constant.

Consequently, although K is always a

constant (as will be shown, and equals ·305) at high degrees of superheat, its over-all value, or average value from saturation to the high degree of superheat, must be larger, because of this abnormal increase in its value near saturation.

The engineer will usually only require this average value for different degrees of superheat, and all these values are given in Tables XII. and XIII.

For boiler tests and engine or turbine trials using superheated steam, these values are essential.

It was a pleasant surprise to find how very accurately did superheated steam obey Joule's law, better even than the so-called perfect gases, as shown in the Joule-Thomson experiments.

The Fundamental Principle of the Experiments.

If steam flows from a zone of high pressure to a lower pressure, the total heat per lb. of steam at the high pressure will be equal to the total heat per lb. of steam at the lower pressure, provided:—

The high pressure remains constant;
The quality of the high pressure steam remains constant;
There is no loss by radiation;
And the lower pressure steam does no external mechanical work, as the moving of a piston, *i.e.*, it must expand freely into the zone of lower pressure.

This fact is self-evident, for we cannot create or destroy heat, and therefore if there is no loss by radiation or mechanical work (other than that included in the total heat) performed the total heat per lb. of steam at the high pressure must equal the total heat per lb. at the lower pressure.

By the quality of the steam we mean its degree of wetness or superheat, or it may be exactly dry saturated, *i.e.*, neither wet nor superheated.

Let us keep the high pressure steam at constant pressure and of constant quality, then by varying the lower pressure we obtain various qualities of low pressure steam, but each quality contains the same amount of total heat, for each equals the total heat at high pressure per lb. of steam.

Now, suppose there is a loss by radiation, but that it remains constant, then the total heat per lb. of steam at the various low pressures, will still remain constant, for they each equal the total heat at the high pressure, less the loss by radiation which is a constant quantity.

Let the steam in the lower zone be superheated.

It matters not what quality or pressure of steam we have in the high pressure zone; so long as they remain constant and the loss by radiation remains a constant.

Let the pressure in the lower zone be measured by a mercury manometer and the temperature by a very accurate thermometer and let us vary the pressure as we will with a valve (see Fig. 2).

Let p_1, p_2 be the low pressures, which we vary at will, t_1, t_2 the corresponding temperatures of the saturated steam in degrees F., and let T_1, T_2 be the temperatures in degrees F., as read by the thermometer.

That is (T_1-t_1) and (T_2-t_2) are the degrees of superheat of the steam at the pressures p_1, p_2.

Now the total heat (H) of saturated steam, as found in all standard tables of the properties of saturated steam, is calculated from an empirical formula deduced by Regnault from his experiments, viz.—

$$H = C + \cdot 305\ t,$$

where $C = 1114$ if t is in degrees F.

Then the total heats (H and H'_2) of our superheated steam at temperatures T_1 and T_2, and pressures p_1 and p_2, are:—

$$H'_1 = C + \cdot 305\ t_1 + K^{t_1}_{T_1}\ (T_1 - t_1)$$

and $$H'_2 = C + \cdot 305\ t_2 + K^{t_2}_{T_2}\ (T_2 - t_2)$$

And $H'_1 = H'_2$

where $K^{t_1}_{T_1}$ = average specific heat at constant pressure from O degrees to (T_1-t_1) degrees of superheat.

$K^{t_2}_{T_2}$ = average specific heat at constant pressure from O degrees to (T_2-t_2) degrees of superheat.

Hence we have—

$$\cdot 305\ (t_2 - t_1) = K^{t_1}_{T_1}\ (T_1 - t_1) - K^{t_2}_{T_2}\ (T_2 - t_2) \qquad (1)$$

We have no right to assume $K^{t_1}_{T_1} = K^{t_2}_{T_2}$, for as yet we know nothing of the value of the specific heat of superheated steam, nor how its value varies for different degrees of superheat at constant pressure, or for different pressures at constant degrees of superheat. Indeed, as will be seen later, these average values from saturation for K are not equal.

We shall now examine the results of the experiments, that is, how the temperature T, as read by the thermometer, varies for different pressures read by the manometer.

Main Results of Experiments. — During each set of readings the high pressure steam is kept at constant pressure, and of constant quality. Only the lower pressure steam is varied in pressure and the corresponding temperatures (T) of the superheated steam behave as follows :—

1. If the superheat is above 16° F. at atmospheric pressure, and above 3·5° F. at 150 lbs. per sq. in. pressure, the temperature T remains constant for all variations in the pressure (p).

2. If the superheat is less than 16° F. at atmospheric pressure, and less than 3·5° F. at 150 lbs. per sq. in. pressure, then as the pressure (p) is raised T rises also, but T rises slower than t, and hence the superheat decreases as we raise the pressure, till finally there is no superheat and $T = t$.

This total rise of temperature T we will call Q.

It is the rise in degrees Fahrenheit of T from the point of no variation to the point of saturation ; in other words, the maximum Joule - Thomson "cooling effect" for a given pressure. The point of no variation is at 16° F. superheat at atmospheric pressure and at 3·5° F. superheat at 150 lbs. per sq. in. pressure.

At atmospheric pressure $Q = 16{\cdot}4°$ F.

At 150 lbs. per sq. in. pressure $Q = 1{\cdot}5°$ F.

Deductions.—Let the letters K_1, K_2, K_T, &c., denote the specific heat of superheated steam under constant pressure, and at a given degree of superheat, 1 degree, 2 degrees, or T degrees.

And let $K_1^{t_1}$, $K_2^{t_1}$, $K_3^{t_2}$, $K_{T_2}^{T_1}$ denote the average specific heat of superheated steam under constant pressure, over a range of superheat denoted by the suffixes, that is from the points of saturation t_1, t_2, or some degree of superheat T_1 to any other given amount of superheat 1 degree, 2 degrees, 3 degrees, or T_2 degrees.

At high degrees of superheat K_T will very nearly equal K_T^t.

Result of no Variation.—From result (1) it at once follows that K_T the specific heat of superheated steam at all degrees of superheat above 16° F. for atmospheric pressure and above 3·5° F. for 150 lbs. pressure per sq. in. is a constant and equal to ·305.

For by raising the pressure from p_1 to p_2 or t_1 to t_2 (the corresponding saturation temperatures). The heat absorbed by the saturated steam in raising its temperature from t_1 to t_2 is equal to the amount of heat given up by the superheated steam in having its superheat reduced. Now the heat absorbed by the saturated steam is equal to $\cdot305\ (t_2 - t_1)$.

And the heat given up by the superheated steam = (the average specific heat) × (the fall in degrees of superheat).

(The fall in degrees of superheat) = (the rise in degrees of the saturated steam) = $(t_2 - t_1)$, because the temperature T does not vary.

Hence we have

$$\cdot305\ (t_2 - t_1) = K_T\ (t_2 - t_1) \qquad (2)$$
$$\text{or } K_T = \cdot305.$$

This value of K_T is the value at the amount of superheat and not the average value from saturation $\left(\frac{Kt}{T}\right)$ as might first be supposed. It is the average value over the decrease in the superheat, and being always equal to ·305 is therefore a constant. This equation (2) holds so long as the temperature T does not vary.

It may be argued—

$$\text{1st total heat} = C + 305t_1 + K_T^{t_1}(T - t_1) \qquad (3)$$

$$\text{2nd total heat} = C + \cdot305t_2 + K_T^{t_2}(T - t_2) \qquad (4)$$

therefore

$$\cdot305\ (t_2 - t_1) = K_T^{t_1}(T - t_1) - K_T^{t_2}(T - t_2) \qquad (5)$$

and that not knowing $K_T^{t_1}$ or $K_T^{t_2}$ we can go no further, as is the case with equation (1).

But from the areas in Fig. 1 we see that

$$K_{T_1}^{t_1}(T - t) = K_T^{t_2}(T - t_2) + K_T\ (t_2 - t_1) \qquad (6)$$

and therefore substituting we have

$$\cdot305\ (t_2 - t_1) = K_T\ (t_2 - t_1) \text{ as above;}$$

so that K is the value at any given amount of superheat above 16° F. at atmospheric pressure and above 3·5° F. at 150 lbs. per sq. in. pressure and is equal to ·305.

The same result is obtained by making $T_2 = T_1$ in equation (8) for the general case.

The General Case when T Varies.—Let OX and OY be two rectangular axes, Fig (1).

Let OX represent temperature marked off in degrees Fahrenheit. Mark off to any convenient scale $OC = \cdot305$ along OY and draw CD parallel to OX.

Then a rectangular area, enclosed between

CD and OX and any temperatures of saturation t_2 and t_1, represents the difference in total heat units of saturated steam at temperatures t_2 and t_1, and $= \cdot 305\ (t_2 - t_1)$.

And if quantities along the axis OY represent the specific heat of superheated steam at any temperature to the same scale as $OC = \cdot 305$ for saturated steam, we may have any specific heat curve AA, whose ordinates parallel to OY represent the specific heat of superheated steam at the temperatures they (the ordinates) are drawn from.

The any area enclosed between any part of the curve AA, and two ordinates at any temperature T_1, T_2, will represent heat units given up or taken in (as the case may be) by changing the temperature of the superheated steam from T_1 to T_2.

The two curves A_1A_1 and A_2A_2 are identical.

Let the thermometer read T_1 degrees F., which is the temperature of the superheated steam, and let the pressure p_1 have a corresponding saturation temperature t_1 degrees F. as before.

Then the superheat $= (T_1 - t_1)$ degrees F.

We then raise the pressure slightly to p_2 and corresponding saturation temperature t_2 degrees F. and T_1 at once rises to T_2. The superheat is now $(T_2 - t_2)$ degrees F.

The total heat of the superheated steam remains constant during this operation.

As before, therefore—

The heat absorbed by the saturated steam in raising its temperature from t_1 to t_2 is equal to the heat given up by the superheated steam in having its superheat reduced. Now the heat absorbed by the saturated steam $= \cdot 305\ (t_2 - t_1)$ (6). And the heat given up by the superheated steam is

$$= K \frac{T_1 - t_1}{T_2 - t_2} \left\{ (T_1 - t_1) - (T_1 - t_2) \right\} \qquad (7)$$

Therefore equating (6) and (7) we have—

$$(yy) = K \frac{T_1 - t_1}{T_2 - t_2} = \frac{\cdot 305\ (t_2 - t_1)}{(t_2 - t_1) - (T_2 - T_1)} \qquad (8)$$

If the difference between the superheats $(T_1 - t_1)$ and $(T_2 - t_2)$ is small, as they are in the actual experiments, there is very little error in assuming $K \frac{T_1 - t_1}{T_2 - t_2}$ as the value of K at the middle point between the two superheats.

In the figure it is represented by yy.

Geometrical Proof. — The shaded areas represent the two equal portions of heat exchanged and equated above.

The proof may be followed geometrically by superposing the curve $A_2\ A_2$ on $A_1\ A_1$ so that the ordinate at t_2 falls on t_1 and T_2 on T''.

With the aid of a piece of tracing paper it is clearly shown that the shaded areas are the gain and loss of heat, and they must be equal, because the total heat remains constant.

So we have the length of the ordinate yy known from equation (9), and it equals

$$yy = \frac{\cdot 305\ (t_2 - t_1)}{(t_2 - t_1) - (T_2 - T_1)} \qquad (8)$$

t_2 and t_1 are known because the manometer registers are corresponding pressures, and $(T_2 - T_1)$ is the rise of temperature read by the thermometer.

So, by varying the degrees of superheat from saturation to 16° F. superheat, we obtain different values of K for each degree of superheat, because the thermometer rises most near saturation; and over 16° F.

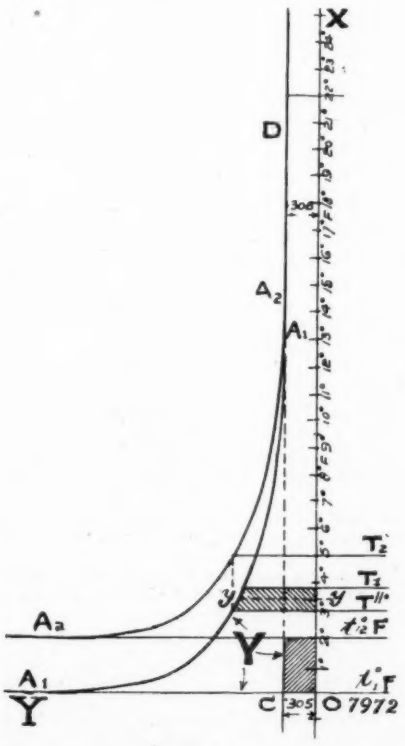


FIG. I.

superheat at atmospheric pressure of 3·5° F. at 150 lbs. per sq. in. pressure, the thermometer shows no variation whatever, even for large changes of pressure.

Hence, if we put $T_2 = T_1$ in equation (8) we have

$$K = \cdot 305 \text{ as before.}$$

To find the value of the Area Y (Fig. 1).—Since the maximum rise of temperature Q, that is from 16° F., superheat to saturation is = 16·4° F. (see result (2) then $T_2 = t_2$

$$\text{and } (T_1 - t_1) = 16\cdot 4° \text{ F.}$$

Substituting these values in equation (8) we have

$$K \frac{16}{0} = \frac{\cdot 305\,(16 + 16\cdot 4)}{(16 + 16\cdot 4) - 16\cdot 4}$$

$$= \frac{\cdot 305\,(32\cdot 4)}{16} = 0\cdot 618$$

Let Y = area enclosed by the specific heat curve AA and the area OY and CD.

$$Y - (K \frac{16}{0} \times 16) - (\cdot 306 \times 16) \qquad (9)$$

$$= 16 \times (\cdot 618 - \cdot 305)$$

$$Y = 5\cdot 0 \text{ at atmospheric pressure.}$$

Or the value of Y may also be deduced as follows:—It is the same proof put differently.

The total heat above saturation in the superheated steam, at a superheat of $(T_1 - t_1)$ is

$$= Y + \cdot 305\,(t_2 - t_1)$$

and this is the heat given up from the superheated steam if the pressure is raised till there is just no more superheat, that is till $t_2 = T_2$ exactly.

Now this is equal to the heat absorbed by the saturated steam due to the rise of pressure

$$= \cdot 305\,(t_2 - t_1)$$
$$= \cdot 305\,(T_2 - t_1).$$

Therefore we have

$$Y + \cdot 305\,(T_1 - t_1) = \cdot 305\,(T_2 - t_1)$$
$$\text{therefore } Y = \cdot 305\,(T_2 - T_1)$$
$$\text{that is } Y = \cdot 305 \times Q. \qquad (10)$$

So at atmospheric pressure

$$Y = \cdot 305 \times 16\cdot 4 = 5\cdot 00$$

and at 150 lbs. per sq. in. pressure

$$Y = \cdot 305 \times 1\cdot 5 = \cdot 46.$$

Description of the Experiments and the Specific Heat Curves plotted graphically.

Arrangement of the Apparatus Used (see Fig. 2).—Rain water was used in the boiler, and on being tested gave results as good as distilled water.

The pressure in the boiler could be regulated to a nicety by varying the heating lamps, according to the demand for steam.

Three throttle discs were used with different sized holes, the smallest for high pressures, and the larger holes for the lower pressures. The size of the hole made no difference to the test.

The diameter in inches of the hole in each disc was ·07 in., ·05 in. and ·025 in.

The steam from the boiler passes through the superheating coil and is at full boiler pressure till the disc is reached.

Through the small hole in the disc, it passes to the low pressure chamber, surrounds the thermometer and the pressure is registered by the difference in heights of the mercury column manometer.

At B a bottle was inserted to intercept any condensed steam and prevent it forming a column of water over the mercury column.

Measuring Instruments.—The pressure in inches of mercury is corrected for temperature and reckoned as a column of mercury at 32° F.

For the high pressures and large variations in pressure a Bourdon test gauge was used, which had been previously tested by a dead weight oil-testing machine, and set accordingly.

If the thermometer T required a correction, it was of no consequence for only difference of temperature was measured.

Two accurate thermometers were used. The one was graduated into divisions equal to one-tenth of 1° C. and had a range from 0° C. to 31° C.

By shaking some of the mercury into the top reservoir the thermometer read 5·0° C. for a temperature of about 94° C.

The other thermometer was graduated likewise to one-tenth of 1° C., and had a range from 0° C. to 110° C. This thermometer was about 2 ft. 6 ins. long and ⅜ in. in diameter.

By driving some of the mercury into the top reservoir, the thermometer read 5° C. at a temperature of 136° C.

For the determination at temperatures above the critical temperature of steam (688° F.) a nitrogen compressed mercury-in-glass thermometer was used.

The thermometers were calibrated by taking a series of readings for saturated steam, with the corresponding pressures, before each test or series of tests was begun, and then comparing these figures with saturated steam tables, whose temperatures are those of the air thermometer.

Only for one set of experiments was a slight correction needed.

The Tests.—Each separate test only lasted usually one minute, except in special cases, where a series of readings were taken at

regular intervals of time. But each group of tests took about three hours; or more, if equilibrium could not be obtained.

The readings taken for 0·1° F. to 2° F. of superheat are numerous and duplicate each other very well.

But from 2° F. to the point of no variation equilibrium is difficult to maintain.

If equilibrium was at all disturbed, the thermometer did not return to its initial temperature.

An Example.—Take test No. 39, Table VII. Steam is flowing at a constant rate through the disc and chamber.

When the thermometer reads 5·32° C. we know it has a slight superheat, for the saturation temperature at that same pressure was determined before we increased the superheating lamp, *i.e.*, when the steam was wet saturated and found to be 5·10° C.

We wait till the thermometer remains quite steady and there is complete heat balance. Then quickly take the reading and raise the pressure a little over an inch of mercury. The thermometer responds at once, and rises quickly and definitely to 6·41° C.

Quickly read the pressure (it is best to bring the mercury always to a definite mark so as not to delay too long) and then the temperature, and again lower the pressure to zero as at the start.

If the equilibrium has not been disturbed the thermometer returns to the initial temperature.

Equilibrium or Heat Balance.—It will be noticed from the tables that the temperature does not usually return to exactly the same degree, but the differences are extremely small, and in calculating K, the mean of the two temperatures is taken.

It must be remembered that the thermometer is graduated to $\frac{1}{10}$ of 1° C. We can, therefore, easily detect $\frac{1}{100}$ of 1° C. rise or fall, and we can read fairly accurately to $\frac{1}{50}$ of 1° C., *i.e.*, ·02° C.

Indeed, if the temperature returns to within ·05° C. it may be considered very good.

With more than 2° F. superheat and less than 16° F., the temperature is erratic and equilibrium is only attained after hours of watching, also the temperature rise or fall is extremely slow, and it is difficult to decide when the limiting point is reached. For this reason there are only six successful tests above 2° F. superheat to the point of no variation 16° F. But since the curve AA, Fig. 3, is almost a straight line at these points, and we have three points at 7·6° F. superheat, we do not require more to plot the curve AA, at these degrees of superheat where equilibrium is so erratic.

Virtues of Superheated Steam Joints.—Engineers who have had to deal with superheated steam practically, must have been struck by the ease with which joints in piping are made steam tight. This was very clearly shown at times during these experiments.

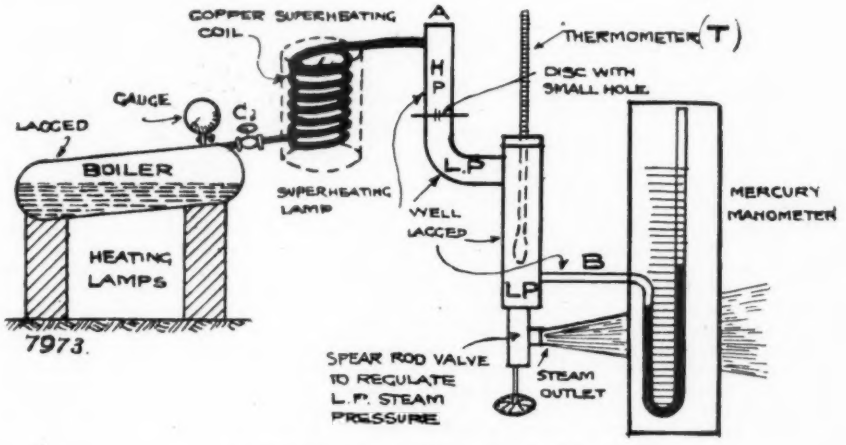


FIG 2.—DIAGRAMMATIC SKETCH OF APPARATUS USED.

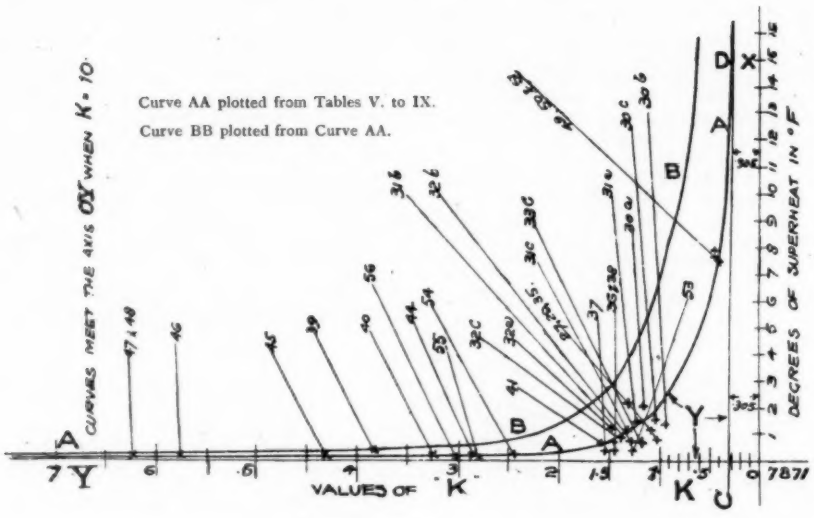


FIG. 3.

The pressure of steam had first to reach its maximum before superheating could be applied; and occasionally a joint would actually be blowing under the saturated steam's pressure. But when the steam became superheated, the joint would take up and remain quite steam tight, till the steam was again brought to the state of saturation or wetness, when it would at once begin leaking again.

The joints are always easier to keep tight with the steam well superheated.

Economy of Superheated Steam. — Then again the economy of using superheated steam was brought out by the amount which passed through the small hole in the throttle disc.

While the steam was wet or saturated, the heating lamps under the boiler had to be kept at full blast to keep up the pressure.

But when the superheating lamp was applied and the steam became superheated, the boiler lamps could be very considerably lowered and yet keep up the pressure.

The superheating lamp, no doubt, supplied more energy in the system, but it did not supply energy in the form of heat sufficient to compensate that saved by lowering the boiler lamps.

There was less fuel used to keep up a constant given pressure, when the steam was superheated, than when it was wet or saturated.

The exact reason for this economy is not assigned here; nor was any test made involving measurement of the economy produced. Sufficient was the work of the tests then at issue; but these facts could not but strike one's notice in passing.

Another Method on the same Principle (see Appendix). — The tests might have been carried out by reading another thermometer inserted at *A* (Fig. 2), on the other side of the disc (see Section VII.).

But there is much, practically, against this alternate method. Two different thermometers are used, there is a considerable radiation correction to be applied and the thermometers are in different parts of the instrument. By varying the pressure on the lower side, the same thermometer is used and under exactly the same conditions are the two readings taken, and the interval of time is not more than a minute, usually, and very often less.

It matters not what the pressure or state of the steam is on the boiler side of the disc, so long as the steam when it surrounds the thermometer *T* on the lower side is at the required degree of superheat.

Whether it has been superheated by the throttling action of the disc, by friction through the disc or against the sides of the instrument, or eddy currents or molecular attractions, or directly by the superheating lamp, is of no consequence whatever.

So this method of varying the pressure on the lower side of the disc, and using two readings by the same thermometer, was adopted as being the easier to perform, taking less time and withal far more accurate.

Some Details of the Experiments.—The sketch of the apparatus used in Fig. 2 only pretends to be a diagram of the general arrangement. The thermometer was not naked in the steam chamber as shown, but inserted in a brass pocket, the walls of which were about $\frac{1}{32}$ in. thick, and the pocket was filled with mercury.

The boiler pressure, too, was often read by a thermometer inserted in another pocket in the saturated steam.

The steam was generated with two powerful paraffin vapour blow lamps of the "Primus" type, their nipples being enlarged to increase their power.

The best means of keeping them at a constant rate of burning was to mix a certain amount of petrol with the paraffin oil about 1 to 1 ratio. Then when the body or cistern of the lamp became heated to a constant temperature by radiation from the boiler and sides of the enclosure, the petrol vapour created the internal pressure corresponding to its temperature, and the lamp did not need to be re-pumped, but the blast remained steady, so long as the general temperature was steady, petrol being so easily vaporised.

The superheating coil was of copper, $\frac{1}{4}$ in. outside diameter and $\frac{3}{32}$ in. inside; much the same as is used on a sight feed lubricator.

TABLE I.

No of Test.	Pressure in Chamber in in. of Mercury.	Temperature in Chamber, degrees C. T.	Boiler Pressure in lbs. per sq. in. Gauge.	Superheat in degrees F.	K.
	in.				
1	0	25·50	35	36·9	·305
	7	25·50		over 16	
2	0	26·30	35	38·3	·305
	7	26·30		over 16	
3	0	26·80	35	39·2	·305
	7	26·80		over 16	
4	0	33·20	35	50·8	·305
	8·4	33·20		over 16	
5	0	30·50	36	45·9	·305
	9·4	30·50		over 16	
6	0	30·50	36	45·9	·305
	12	30·50		over 16	
7	0	14·00	32	16·17	·305
	2·1	14·00		13	
8	0	34·90	32	53·8	·305
	10	34·90		over 16	
		deg. F.			
9	0	285	15	83	·305
	10	285		over 16	

Notes.—(TABLE I.). Thermometer graduated to one-tenth of 1° C.

Boiling point of water at atmospheric pressure equals 5·00° C. Barometer equals 24·5 ins. of mercury, which is usually a dead constant for all weathers and seasons. Thermometer in No. 9 graduated in 2° F., and its boiling point for water at atmospheric pressure equals 202° F.

TABLE II.

No. of Test.	Pressure in Chamber in in. of Mercury.	Temperature in Chamber, degrees C. T.	Boiler Pressure in lbs. per sq. in. Gauge.	Superheat in degrees F.	K.
	in.				
10	0	292	75	90	·305
	10	292		73	
11	0	342	87	140	·305
	12	342		120	
12	0	433	50	231	·305
	12	433		211	
	lbs. per sq. in.				
13	0	434	48	232	·305
	20	434		180	
14	0	364	80	162	·305
	15	364		120	
15	0	364	80	162	·305
	15	364		120	
16	40	386	108	103	·305
	70	386		72	
17	60	383	108	78	·305
	90	383		54	
18	107	396	175	56	·305
	135	396		39	
19	95	396	175	63	·305
	145	396		34	
20	100	397	175	61	·305
	150	397		33	

Notes.—(TABLE II.) Thermometer graduated to 2° F. and 1° C. Could not detect a rise or fall of $\frac{1}{10}$° F. for the change of pressure. For an error of $\frac{1}{10}$° F. in the readings, the value of *K* is altered to—

$$\cdot 305 \times \frac{29}{29 \cdot 1} = 304 \text{ in Nos. 19 and 20.}$$

Boiling point of water equals 202° F.

In Table III., when the superheat was raised above the critical temperature of steam (*i.e.*, above 688° F.) the coil was at a dull red heat, and withstood the pressure of 120 lb. per sq. in. without the least sign of contortion.

The issuing steam was quite invisible, but the hand could easily be held in it without scalding, and it might have been warm compressed air from all appearances. In this experiment, too, the leaden joint at the disc was replaced by one of asbestos, as lead would have melted in the superheated steam.

TABLE III.—ABOVE THE CRITICAL TEMPERATURE OF STEAM.

No. of Test	Pressure in Chamber in lbs. per sq. in. by Gauge.	Temperature in Chamber deg. F. T.	Boiler Pressure lbs. per sq. in. Gauge.	Superheat in deg. F.	K
	in.				
	0	640			
21	50	640	123	420	·305
	0	640		345	
	0	759			
22	60	759	121	557	·305
	0	759		454	
	0	755			
23	30	755	120	553	·305
	0	755		485	
	0	710			
24	100	710	113	508	·305
	0	710		374	

Notes.—(TABLE III.) The mercury in the cup in which the thermometer was inserted, boiled over, the thermometer remaining constant as long as any mercury remained in the cup. The temperature read 668° F. As soon as the cup was empty the temperature rose rapidly to 759° F.

The copper superheating coil appeared to be at a dull red heat, and the superheating lamp flame at the time was very powerful.

Boiling point of mercury (Regnault) is 675° F. probably at sea level barometer pressure.

The *critical temperature of steam*, determined by Batelli is 688° F. and the corresponding critical pressure is 2,826 lbs. per sq. in.

The thermometer had a range from 0° F. to 1,000° F., was mercury-in-glass with compressed nitrogen above the mercury, and was graduated to 2° F.; and 0·2° F. would be the experimental error, and this affects the value of K by ·0006 in Test No. 22.

It would seem from these large variations in pressures, and yet with no variation in T, that either the value of **Y** is the same at all pressures (but the figures in Table X. shows that **Y** diminishes at high pressures) *or that* $\frac{d\ H}{d\ \theta}$ *for saturated steam does not exactly follow a linear law, as determined by Regnault.* (See Appendix.)

This point should be more fully investigated by experiment. But, as remarked elsewhere, the determination of Q or **Y** in one operation at various pressures is a difficult experiment to hit off.

TABLE IV.

No. of Test.	Pressure in Chamber in lbs. per sq. in. Gauge.	Temperature in deg. C. T.	Boiler Pressure Gauge.	Superheat in deg. F.	K
25	20	93·65	80	181	·305
	40	93·65		152	
	10 11	93·30			
	10 11	93·30	80	202	·305
26	30 11	93·30		165	
	30	93·30			

Notes.—(TABLE IV.) Thermometer graduated $\frac{1}{10}$° C.
Correction = 1·31° C.
Error of observation = ·02° F.
In Test No. 26, for this maximum error in the reading, K is altered by ·0002.

TABLE V.—VARIATION.

The test Nos. with a cross *x* denote those plotted for the curve AA, Fig. 3.

No. of Test.	Pressure in Chamber in in. of Mercury. p	Temperature in deg. C. in Chamber T.	Boiler Pressure in lbs. per sq. in. Gauge.	Superheat in deg. F.	K.	Middle Point of Superheat, deg. F
	in.					
	0	5·40		·95		
27*x*	·36	5·90	30	·63	1·03	·79
	0	5·55				
	0	5·70		1·44		
28	·73	6·40	30	1·20	1·79	1·32
	0	5·80				
	0	6·30		2·34		
29*x*	·73	6·90	28	2·01	1·30	2·18
	0	6·15		2·16		
	·73	6·73	28	1·79	1·16	1·98 (*a*)
30*x*	2·14	7·75		0·91	1·01	1·35 (*b*)
	0	6·15		2·16		1·54 (*c*)
	0	5·84		1·60		
	·73	6·43	28	1·25	1·23	1·43 (*a*)
31*x*	2·14	7·60		0·65	1·36	0·95 (*b*)
	0	5·84		1·60	1·32	1·13 (*c*)
	0	5·68		1·31		
	·73	6·30	28	1·02	1·48	1·17 (*a*)
32*x*	2·14	7·45		0·38	1·29	0·70 (*b*)
	0	5·68		1·31	1·37	0·85 (*c*)
	0	5·60		1·17		
	·73	6·30	28	1·02	2·86	1·10 (*a*)
33*x*	2·14	7·30		0·10	0·90	0·56 (*b*)
	0	5·60		1·17	1·19	0·64 (*c*) *x*

Notes.—(TABLE V.) Let $dp = (p_2 - p_1)$ and $d\theta = (t_2 - t_1)$
Then dp = ·73 in., $d\theta$ = 1·41° F.
dp = 1·41 in., $d\theta$ = 2·72° F.
dp = 2·13 in., $d\theta$ = 4·12° F.

Barometer equals 24·50 in. mercury.

Boiling point of water at atmos. pressure equals 4·95° C. at start of tests 3·0 p.m.

B.P. of water at atmos. pressure equals 5·00° C. at finish of tests 5·10 p.m. by the same thermometer graduated to $\frac{1}{10}$° C.

Maximum Rise of Temperature or Determination of Y.

The real figure we wish to attain is Q, the total rise of T from the point of no variation to the state of saturation. The most accurate method of doing this is by summing up each separate rise of T over a small range of superheat. If we try and take a longer range, equilibrium troubles again come in, only, however, at atmospheric pressures; whereas at high pressures of 150lbs. per sq. in. the total rise Q is comparatively small and can be fairly accurately determined in one operation.

It seems that as we raise the pressure, and consequently the saturation temperature, the area **Y** greatly diminishes, and it seems only natural to suppose the area **Y**

TABLE VI.—VARIATION.

No. of Test.	Pressure in in. of Mercury in Chamber.	Temperature in deg. C. in Chamber. T	Boiler Pressure in lbs. per sq. in Gauge.	Superheat in deg. F.	K.	Middle Point of Superheat, deg. F.
	in.					
	0	5·45		·99		
34	1	6·15	69	·32	0·88	·66
	0	—				
	0	·70		1·31		
35x	1	6·40	69	·87	1·09	1·09
	0	5·55				
	0	5·40				
36x	1	6·25	69	·90	1·47	·7
	0	—		·50		
	0	5·25				
37x	1	6·10	69	·61	1·55	42
	0	5·22		·23		
	0	5·25				
38x	1	6·10	69	·63	1·47	43
	0	—		·23		

Notes.—(TABLE VI.) dp=1 in., $d\theta$=1·93° F. B.P. of water at atmos. pressure = 4·90° C. by the thermometer used.

TABLE VII.—VARIATION.

No. of Test.	Pressure in ins. of Mercury in Chamber.	Temperature in deg. C. in Chamber. T.	Boiler Pressure in lbs. per sq. in. Gauge.	Superheat in deg. F.	K.	Middle - Point of Superheat, deg. F.
	in.					
	0	5·32		·39		
39x	1·11	6·41	68	·22	3·84	·31
	0	5·31				
	0	5·30				
40x	1·11	6·36	68	·32	3·27	·22
	0	5·25		·12		
	0	—				
41x	1.11	6·68	68	·71	1·59	·92
	0	5·72		1·12		
	0	—				
42	1·11	6·79	68	·91	3·11	1·02
	0	5·72		1·12		
	0	7·10				
43	1·11	8·05	68	3·60	1·67	3·41
	0	7·05		3.21		

Notes.—(TABLE VII.). dp = 1·11 ins., $d\theta$ = 2·14° F.
No. 43 was very slow indeed, the rising of the thermometer taking some eight or ten minutes. At *temperatures* 7, 8, 9, 10 and 11° C. the rise of temperature is extremely sluggish, and it is almost impossible to obtain figures at these degrees of superheat.
Temperature of saturated steam by the thermometer at atmos. pressure is 5·10° C.

to vanish altogether when the critical pressure, 2,826 lbs. per sq. in., is reached, *i.e.*, the total heat of the saturated steam, and also of the superheated steam, at or near the critical temperature and pressure, increases uniformly per degree rise of temperature from the state of saturation to the superheated state, and the increase is ·305t, or ·305T.

In Fig. 1, therefore, at the critical pressure and temperature there would be no curve AA, for it would have gradually

TABLE VIII.—VARIATION.

No. of Test.	Pressure in Chamber in ins. of Mercury.	Temperature in deg. C. in Chamber. T.	Boiler Pressure in lbs. per sq. in. Gauge.	Superheat in deg. F.	K.	Middle - Point of Superheat, deg. F.
	in.					
	0	5·38		·32		
44x	1·11	6·44	33	·20	2·84	·26
	0	—				
	0	5·24		·16		
45x	1·17	6·39*	33	·00	4·31	·08
	0	5·21				
	0	5·20		·12		
46x	1·17	6·39*	30	·00	5·74	·06
	0	5·21				
	0	5·20		·11		
47x	1·17	6·40*	30	·00	6·25	·06
	0	5·20				
	0	5·20		·11		
48x	1·17	6·38*	30	·00	6·25	·06
	0	5·20				
	0	9·50		8·3		
49x	1·17	10·10	30	6·8	·455	7·6
	0	9·80				
	0	9·70		8·3		
50x	1·17	10·05	29	6·6	·405	7·5
	0	9·80				
	0	9·80		8·5		
51x	1·17	10·20	29	7·0	·455	7·8
	0	9·60				

Notes.—(TABLE VIII.). Saturation temperature in chamber at atmos. pressure equals 5·14° C. before and after the experiments. At 16·7° C. *temperature* there is apparently *no variation*, *i.e.*, at 20·8° F. superheat.
* These temperatures are temperatures of saturation as near as can be.
For Nos. 45, 46, 47 and 48 K is therefore calculated as follows :—

Taking $T_2 = t_2$

$$\text{then } K = \frac{\cdot 305\,(t_2 - t_1)}{(t_2 - t_1) - (T_2 - T_1)} \qquad (8)$$

$$= \frac{\cdot 305\,(t_2 - t_1)}{T_1 - t_1}$$

Therefore for No. 45

$$K = \frac{\cdot 305 \times 2\cdot 26}{\cdot 16} = 4\cdot 31$$

dp = 1·17 ins., $d\theta$ = 2·26° F. = $(t_2 - t_1)$.

TABLE IX VARIATION.

No. of Test.	Pressure in Chamber in ins. of Mercury.	Temperature in deg. C. in Chamber. T.	Boiler Pressure in lbs. per sq. in. Gauge.	Superheat in deg. F.	K.	Middle - Point of Superheat deg. F.
	in.					
	0	5·10*		0·0		
52	1·26	6·45*	20	0·0	—	—
	0	5·10*		0·0		
	0	5·40				
53x	1·14	6·30*	20	·54	1·27	·28
	0	5·33		·01		
	0	5·33				
54x	1·14	6·34*	22	·31	2·49	·18
	0	5·21		·04		
	0	5·21				
55x	1·14	6·30*	22	·20	2·80	·10
	0	5·21		·00		
	0	5·21				
56x	1·14	6·33*	23	·23	3·05	·12
	0	5·24		·00		

Notes.—(TABLE IX.) Saturation temperature in chamber at atmospheric pressure is 5·10° C.

* The asterisk denotes *at or very near the saturation temperature, i.e., no superheat.*

$dp = 1·14$ in., $d\theta = 2·20°$ F.

At 13·5° C. *temperature*, variation in T was just detected, *i.e.*, at 15·1° F. superheat.

Hence the point of no variation is taken at 16·0° F. superheat.

vanished, as the temperature and pressure are raised, into the straight line *CD*, which would be continuous from the saturated to the superheated state.

K at the Saturation Point.—The approximate value of *K*, as determined by producing the curve *AA*, Fig. 3, through fixed points, till it strikes the axis of saturation *OY* above *A* is 10.

The curve was plotted to large scale, and there are more experimental points on the curve between 0° F. and 0·18° F. superheat than at any other part of the curve, and they all almost lie on a straight line. The value of 10 can, therefore, be fairly accurately gauged.

Hence the specific heat *K* of superheated steam just above the point of saturation is 10·0, at atmospheric pressure, or nearly 33 times its constant value at higher degrees of superheat.

Experimental Difficulties between 2° F. and 16° F. superheat at atmospheric pressure.

The difficulty of obtaining satisfactory readings at atmos. pressure between these degrees of superheat, can only be realised by trying the experiment. The thermometer either continues to fall very slowly, then if the superheating lamp is raised ever so little, the thermometer continues to rise and will not keep steady between 2° F. to 16° F. superheat.

The following figures in Table X show the total rise in *T* from about 5° F. to 16° F. superheat. This is over a considerable range of temperature and therefore the value for $K_{\frac{1}{16}}^{A}$ will not be its value at the middle point of superheat, viz., at about 10·5° F., unless the curve *AA* were a straight line, which it is not.

The calculated figures then in Table X. for *K* are bracketed.

But the results in this table are necessary in estimating *Q*, the total rise of *T* from 16° F. to 0·0° F. superheat at atmospheric pressure. The first slope of the curve in Fig. 4 from 16° F. to 8·4° F. superheat is based on the figures deduced in Table X.

Q equals the maximum value of $(T_2 - T_1)$ for any given pressure.

Difficulties of a Physical Nature.—The pressures, though not atmospheric in Table X., do not give values different from those obtained on the curve at atmospheric pressure for the same degrees of superheat.

Were this experiment as easy to carry out as those for Tables I. to IX., the value of *Q* and therefore of **Y** might be determined for the intermediate pressures between atmospheric and 150 lbs. per sq. in.

The difficulty does not lie in the want of accurate thermometers or manometers, but the equilibrium always seems to be upset about the point of no variation.

For hours I have watched the thermometer (graduated to $\frac{1}{10}$° C.) expecting equilibrium any moment, till the boiler has steamed itself dry and one must begin afresh.

After whole days of this monotony the figures in Tables X. and XI. were obtained.

Error in Q of small account.—And even if the value of *Q* is not very accurate (and it cannot be far wrong), it must be multiplied by ·305 to obtain **Y**, and a small error in **Y** has little effect on the values of *K*, in Tables XII. and XIII. the specific heat values for engineers.

If *Q* is a whole degree wrong at atmospheric pressure the value of K_{20}^{0} at 20° F. superheat is only altered by ·015.

And at 100° F. superheat, 1° in *Q* is equivalent to ·003 error in K_{100}^{0}.

Whereas at high pressures of 150 lbs. per sq. in., where $Q = 1·5$° F., an error of 33 per cent. or ·5° F. alters K_{20}^{0} at 20° F. superheat by ·008 only, and at 100° F. superheat by ·0015.

For all engineering purposes, therefore,

this error is insignificant, and it only applies to the curve *BB* for engineers.

It does not affect the curve *AA* except from 16° F. to 2° F. at atmospheric pressure, and at high pressures from 3·5° F. superheat to saturation.

TABLE X.—VARIATIONS IN *T*.

From 16° F. to 5·4° F. superheat *at low pressures*.

No. of Test.	Boiler Pressure in lbs. per sq. in. Gauge.	Pressure in Chamber lbs. per sq. in. Gauge.	Temperature in Chamber deg. C. *T*.	Time Intervals in minutes between Readings.
				min.
		56	22·20	
		56*x*	22·50	1
57	186	32	21·10	1
		32*x*	20·70	1
		55	22·00	
		55	22·30	1
		55	22·50	1
		55*x*	22·70	1
58	186	32	22·30	1
		32	22·00	1
		30	21·70	1
		30	21·50	1
		30	21·40	1
		30*x*	21·35	1
		55	22·30	
		55	22·60	1
		55	22·80	1
		55	23·10	1
		60	23·70	1
		60	24·30	1
59	185	60	24·60	1
		60*x*	25·05	1
		35	24·60	1
		35	24·30	1
		35	24·10	1
		35	23·80	1
		35*x*	23·75	1

The readings opposite the cross (*x*) are the ones taken in the deductions thus—

TABLE X*a*.—DEDUCTIONS.

No. of Test.	Saturation Temperatures in Chamber, Corresponding to the Pressures, as determined by the same Thermometer deg. C.	Temperature in Chamber in deg. C. *T*.	Superheat in deg. F.	Change of T deg. F.	KT^{0}_{16}
57	19·50 5·00	22·50 20·70	5·4 over 16	3·24	(·460)
58	19·00 4·30	22·70 21·35	6·66 over 16	2·43	(·432)
59	21·60 7·50	25·05 23·75	6·21 over 16	2·34	(·415)

TABLE XI.—VARIATION IN T.

Q at High Pressures.

No. of Test.	Boiler Pressure lbs. per sq. in. Gauge.	Pressure in Chamber lbs. per sq. in. Gauge.	Temperature in Chamber deg. C.	Superheat in deg. F.	Q in deg. F. or change of T from 0° F. to 3·5° F. of superheat.	$K^{0}_{3·5}$
60	220	130 158	55·00 55·70	Dry satur. over 10°F.	1·3°F.	·418
61	220	158 130	55·70 54·60	Dry satur. over 10°F.	2·0°F.	·480
62	190	120 100	45·4 44·8	Dry satur. over 10°F.	1·1°F.	·401
63	190	125 100	46·8 45·7	Dry satur. over 10°F.	2·0°F.	·480
64	190	130 100	48·4 47·7	Dry satur. over 10°F.	1·3°F.	·418

Average value of Q=1·5° F. at high pressure.—The saturation temperatures corresponding to the different pressures were determined by the same thermometer and under the same conditions.

The superheat was then raised, by lowering the pressure in the chamber or increasing the superheating lamp. Then the pressure was again raised till the steam just became dry saturated, and the readings were then taken, and repeated by lowering and raising the pressure, to vary the superheat from dry saturation to anything above the point of no variation, which was determined at 3·5° F. superheat.

Calculation of K.—The over all value of $K^{0}_{3·5}$ is calculated from the equation

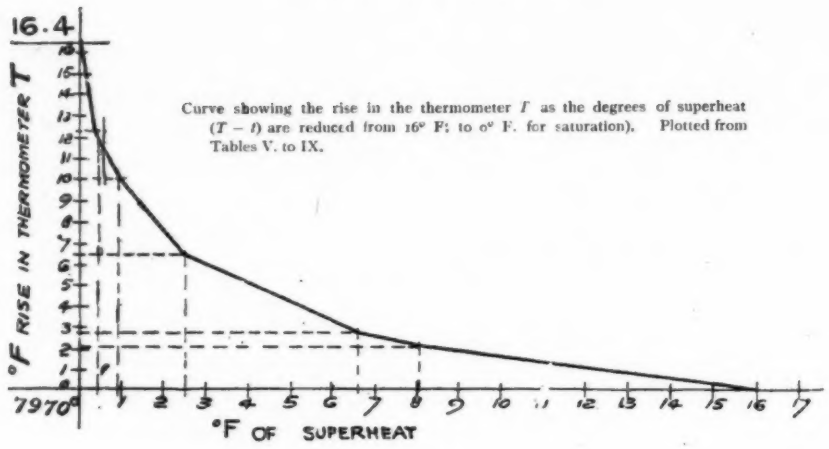
$$K^{0}_{3·5} = \frac{·305 \times (3·5 + Q)}{T_1 - t_1} = \frac{·305 \times (3·5 + Q)}{3·5}$$

Though the experiments differ so much in the value of *Q*, it only affects the second decimal place of *K*, up to 3·5° F. superheat, and with higher degrees of superheat this error is negligible. (See Table XIII.)

The Curves for K and rise of T at atmospheric Pressure.—The Figs. 3 and 4 were first drawn to large scale and then reduced to the scales given here. By this means the area **Y**=5·00 and also the total rise *Q*=16·4° F. were more accurately determined.

Fig. 4 shows how the total rise of temperature from 16° F. to 0° F. (or saturation) of superheat is obtained.

All the tests in Tables V. to IX. were plotted on the large scale, the rise of temperature as ordinates, for so much change of superheat, as abscissæ.



Curve showing the rise in the thermometer T as the degrees of superheat ($T - t$) are reduced from 16° F. to 0° F. for saturation). Plotted from Tables V. to IX.

FIG. 4.

The curve in Fig. 4 is drawn parallel to the average set of lines representing the rise of temperature T for the same degree of superheat. By this means the total rise Q is 16·4° F.

Then $16{\cdot}4 \times {\cdot}305 = 5{\cdot}00 = \mathbf{Y}$ (see Equation 10).

Now, if we run the planimeter over the area **Y** in Fig. 3, p. 121 (taking care of the different scales used) its area will also be 5·00.

This is only a duplicate method of arriving at the same result, and if the results agree, it shows the averaging of the curves in Figs. 3 and 4 are alike.

If each degree of superheat is represented by 1 in., and the unity value of K by 1 in. long, then the area **Y** is 5·00 sq. in. at atmospheric pressure.

High Pressures.—The curve AA has not been determined for high pressures, as it is of no practical use.

The total rise Q (=1·5° F.) is all we require, and the point of no variation, viz., 3·5° F. superheat, so that **Y** at high pressure equals

$$1{\cdot}5 \times {\cdot}305 = 0{\cdot}46 = \mathbf{Y}.$$

To Plot the Curve BB for Tables XII. and XIII.—We can now plot the curve BB (Fig. 3), the ordinates of which represent the average value of the specific heat of superheated steam $\left(K\frac{o^0}{s^0}\right)$ from the saturation point to any given degree of superheat S degrees F.

This curve beyond 16° F. of superheat at atmospheric pressure, and 3·5° F. at 150 lbs. per sq. in. pressure, is a hyperbola, with CD and OY as axes, and the values of $K\frac{o^0}{s^0}$, the over-all specific heat, are given by the equation—

$$K\frac{o^0}{s^0} = {\cdot}305 + \frac{\mathbf{Y}}{S^0} \qquad (11)$$

where S^0 degrees is number of degrees of superheat above the saturation temperature.

For, the total heat of superheated steam at the saturation temperature t_1 degrees F., and S_1 degrees F. superheat (Fig. 3) is—

Total heat = (rectangle ${\cdot}305 \times S^0_1$) + (curved area **Y**).

Therefore the ordinate $K\frac{o^0}{s^0}$ at S degrees F. superheat to the curve BB is

$$\left(K\frac{o^0}{s^0}\right) \times S^0 = ({\cdot}305 \times S^0) + \mathbf{Y}$$

$$\text{or } K\frac{o^0}{s^0} = {\cdot}305 + \frac{\mathbf{Y}}{S^0} \qquad (11)$$

Hence Table XII. is calculated from $K\frac{o}{s} = {\cdot}305 + \frac{5{\cdot}00}{S}$ after 16° F. superheat and Table XIII. is calculated from $K\frac{o}{s} = {\cdot}305 + \frac{{\cdot}46}{S}$ after 3·5° F. superheat.

The first part of the curve *BB* from 0° to 16° F. superheat, begins at *A* (Fig. 3) and the points are plotted from the curve *AA*—

By taking the different areas (between the axes *OY*, *OX* and an ordinate and the curve *AA*) from 0° F. superheat to each degree of superheat and dividing each area by the number of degrees of superheat, this gives the length of the ordinates to the curve *BB* required.

So that every ordinate to *BB* is the average length of all ordinates to *AA* for the same degree of superheat.

TABLE XII.—FOR THE THROTTLING CALORIMETER.

Average Value of the Specific Heat of Superheated Steam (K_S^0) from saturation to S degrees F. superheated at atmospheric pressure.

Superheat in deg. F. S^0	Average Specific Heat from Saturation to S deg. F. Superheat. K_S^0	Superheat in deg. F. S^0	Average Specific Heat from Saturation to S deg. F. Superheat. K_S^0	Superheat in deg. F. S^0	Average Specific Heat from Saturation to S deg. F. Superheat. K_S^0
0·0	10·000	33	0·457	70	0·3764
0·1	7·035	34	0·452	71	0·3754
0·2	5·015	35	0·448	72	0·3744
0·3	4·015	36	0·444	73	0·3735
0·5	3·099	37	0·440	74	0·3726
1·0	2·262	38	0·437	75	0·3717
2·0	1·719	39	0·433	76	0·3708
3·0	1·425	40	0·430	77	0·3699
4·0	1·291	41	0·427	78	0·3691
5	1·166	42	0·4241	79	0·3683
6	1·065	43	0·4213	80	0·3675
7	0·980	44	0·4186	81	0·3667
8	0·909	45	0·4161	82	0·3660
9	0·848	46	0·4137	83	0·3652
10	0·798	47	0·4114	84	0·3645
11	0·755	48	0·4092	85	0·3638
12	0·719	49	0·4070	86	0·3631
13	0·688	50	0·4050	87	0·3625
14	0·662	51	0·4030	88	0·3618
15	0·638	52	0·4012	89	0·3612
16	0·618	53	0·3993	90	0·3606
17	0·599	54	0·3976	91	0·3600
18	0·583	55	0·3959	92	0·3594
19	0·568	56	0·3943	93	0·3588
20	0·555	57	0·3927	94	0·3582
21	0·543	58	0·3912	95	0·3576
22	0·532	59	0·3897	96	0·3571
23	0·522	60	0·3883	97	0·3566
24	0·513	61	0·3870	98	0·3560
25	0·505	62	0·3857	99	0·3555
26	0·497	63	0·3844	100	0·3550
27	0·490	64	0·3831	101	0·3545
28	0·484	65	0·3819	102	0·3540
29	0·477	66	0·3808	103	0·3535
30	0·472	67	0·3796	104	0·3531
31	0·466	68	0·3785	105	0·3526
32	0·461	69	0·3775		

The curve *BB* will be used almost entirely by engineers, and Tables XII. and XIII. represent this curve in figures, for atmospheric pressure and 150 lbs. per sq. in. pressure.

Table of Specific Heats.

Tables XII. and XIII. give the average values of *K* over a range of temperature from saturation to the required degree of superheat.

TABLE XIII

For high pressures, 125—150 lbs. per sq. in. Average value of specific heat of superheated steam (K_S^0) from saturation to S degrees F superheat.

Superheat in deg. F. S^0	Average Specific Heat from Saturation to S deg. F. Superheat. K_S^0	Superheat in deg. F. S^0	Average Specific Heat from Saturation to S deg. F. Superheat. K_S^0	Superheat in deg. F. S^0	Average Specific Heat from Saturation to S deg. F. Superheat. K_S^0
4	0·420	26	0·323	110	0·3092
5	0·397	28	0·321	120	0·3088
6	0·382	30	0·320	130	0·3085
7	0·371	32	0·319	140	0·3083
8	0·363	34	0·319	150	0·3081
9	0·356	36	0·318	160	0·3079
10	0·351	40	0·317	180	0·3076
11	0·347	45	0·315	200	0·3073
12	0·343	50	0·3142	300	0·3065
13	0·340	55	0·3134	400	0·3062
14	0·338	60	0·3127	500	0·3059
15	0·336	65	0·3121	600	0·3058
16	0·334	70	0·3116	700	0·3057
17	0·332	75	0·3111	800	0·3056
18	0·331	80	0·3108	900	0·3055
19	0·329	85	0·3104	1,000	0·3055
20	0·328	90	0·3101		
22	0·326	95	0·3098		
24	0·324	100	0·3096		

At atmospheric pressure the figures in Tables XII. are to be taken, and will be used for the value of *K* in equations (16) and (18) for the Peabody throttling calorimeter.

At high pressures of 125 to 150 lbs. per sq. in., the figures in Table XIII. are to be used.

It will be noticed how these latter figures are rapidly approaching the value ·305. This is on account of the small value of **Y** for high pressures. And at much higher pressures the value of **Y** would become zero and then all values of *K* would equal ·305.

Table XIII. must also be used for equation (12) for determining the total heat of superheated steam at high pressures.

The Total Heat of Superheated Steam.

Let H = total heat of saturated steam as found in the saturated steam tables.

t = temperature of saturated steam in degrees F.

T=temperature of superheated steam in degrees F.

Then $T-t$=degrees F. of superheat and let H'=total heat of superheated steam.

$$H = H + K^{o}_{T}(T-t) \qquad (12)$$

For high pressures of about 125 to 150 lbs. per sq. in. K^{o}_{T} is taken from Table XIII. above, and for atmospheric pressures from Table XII.

Another equation dependent only on the temperature T.

$$\text{Now } K^{o}_{T} = \cdot 305 + \frac{Y}{T-t} \text{ see equation (11)}$$

and $H = 1114 + \cdot 305t$.

Therefore $H' = 1114 + \cdot 305t + \cdot 305(T-t) + \mathbf{Y} = 1114 + \cdot 305\,T + \mathbf{Y}$

Taking $\mathbf{Y} = 5 \cdot 00$ for atmospheric pressures and $\mathbf{Y} = \cdot 46$ for 125 to 150 lbs. per sq. in. pressures.

Then $H' = 1119 + \cdot 305T \qquad (14)$

for atmospheric pressures, when the superheat is above 16° F.

and $H' = 1114 \cdot 46 + \cdot 305T \qquad (15)$

for pressures of 125 to 150 lbs. per sq. in. when the superheat is above 3·5° F.

Radiation Correction, Fundamental Principle Confirmed.

Since the total heat of superheated steam for fairly constant pressures depends only on the temperature, and not at all on the degree of superheat (so long as it is above 16° F. at atmospheric pressure and above 3·5° F. at 150 lbs. per sq. in. pressure), it follows that if we insert a thermometer at A, (Fig. 2), it should register exactly the same temperature as the thermometer T in the low pressure chamber, provided there is no loss by radiation, and that there is not a large difference in the two pressures on either side of the throttle disc.

The only difference between the two thermometer readings can be that due to radiation and to the small difference in pressures. This latter effect will be almost nil.

As this would give a striking and easy proof of the whole principle on which the tests are based, the experiment was carried out.

To prove experimentally the equality of the two temperatures of superheated steam on either side of the throttle disc, their total heat per lb. being the same, but the degree of superheat very different.

Since the total heat per lb. is the same, we must determine the radiation loss.

The Radiation Loss Experiment.—In order to determine the loss by radiation the disc was withdrawn, leaving a clear passage from the valve C to the steam outlet.

Consequently the pressure round both thermometers was very nearly atmospheric.

The rate of flow of steam was kept the same, as when the disc was re-inserted, by keeping the heating lamps under the boiler burning at the same rate, and therefore generating the same quantity of steam per minute; while the valve C was closed sufficiently to throttle the steam by as much as what the disc would, *i.e.*, it was closed till the pressure in the boiler was the same as when the disc was in its position and valve C full open.

The diameter of the hole in the disc was ·07 in.

So the conditions in the two experiments were:—

(1) With throttle disc inserted, valve C full open, boiler lamps burning at a fixed rate, and pressure in boiler equal to 20 lbs. per sq. in. gauge.

(2) No disc, valve C throttled till the boiler pressure remained constant at 20 lbs. per sq. in. gauge, and the boiler lamps burning at the same fixed rate.

There was no practical difficulty in carrying out these conditions.

The conditions in (2) are equivalent to placing the disc at the valve C instead of between the two thermometers.

TABLE XV.

To show the equality of temperature of superheated steam on both sides of the throttle disc, though at different degrees of superheat, only a radiation correction to be allowed for.

Pressure in lbs. per sq. in. on Boiler side of Disc.	Pressure in lbs. per sq. in. on atmos. side of Disc.	Temperature on Boiler side of Disc. degrees C.	Temperature on atmos. side of Disc. deg. C.	Difference between Temperatures degrees C.	Time p.m.
20	0	208·3	197·9	10·4	4—21′
		208·3	197·8	10·5	4—24′
		208·4	197·8	10·6	4—27′
		208·5	197·8	10·7	4—30′
		208·6	197·9	10·7	4—33′

Radiation correction, throttle disc withdrawn and steam throttled at valve C to same extent.

20	0	210·7	200·0	10·7	1—57′
		210·6	200·0	10·6	2—00′
		211·0	200·5	10·5	2—03′
		211·8	201·0	10·8	2—06′

Each experiment was kept going for about two hours altogether, and the readings were steady for about twenty minutes before the above readings were registered, to make sure of the heat flow being quite balanced.

The thermometers were graduated to 1° C. and consequently reading $\frac{1}{10}$° C. was the finest reading possible.

The experiments proved conclusively that any difference in the thermometers was entirely due to radiation.

The readings were too rough to register the slight effect which the difference in pressures would tend to produce.

All the data in Tables I. to XI. might have been got by this method of taking readings, with a thermometer on each side of the throttle disc.

But it is not practicable, due to this radiation correction (which itself takes two hours to become steady), and so the method of varying the pressures on the atmospheric side was adopted as being the easier to carry out and more accurate in its results.

Radiation Loss apparently very large. — The above radiation correction may appear large and even incredible. That steam superheated and flowing from *A*, Fig, 2, to the atmosphere, quite freely along an open well lagged pipe (whose dimensions allowed only of a friction pressure of about ·02 in. of mercury) should drop in temperature 10·5° C. over a distance of about 12 in. may seem at first sight to be wrong.

But it must be remembered that the rate of flow is comparatively very small. The valve *C* is closed till its area to pass steam is only that of a circle ·07 in. in diameter, and the difference of pressure on each side of the valve is only 20 lbs. per sq. in. The size of pipe from *A* to the outlet is $\frac{3}{4}$ in. diameter, and the lagging in both experiments was the same and absolutely dry. (*Vide* the temperature.)

Then again the temperature of the steam is at about 400° F., and therefore the more tends to cool, and, lastly, the specific heat of this steam is only 0·305, and will therefore fall in temperature easier than if it were a higher value.

Taking all these facts into consideration, the drop of 10·5° C. may not seem so excessive.

The Peabody Throttling Calorimeter.

Of all the most ingenious, but simple, instruments used in steam testing, the Peabody throttling calorimeter stands out as the chief and most scientific, and yet can be made of the roughest materials, and, in appearance, may look anything but scientific.

General Equation for the Throttling Calorimeter.—The formula used for determining the wetness of steam with this calorimeter is usually

$$w = 100 \times \frac{H_2 - H_1 - K\,(T - t_1)}{L_2} \qquad (16)$$

Where w = per cent. of wetness in the steam.
H_2 = total heat of saturated steam on the boiler side (measured by the pressure or temperature, the former being the better).
H_1 = total heat saturated steam on the atmospheric side, usually at atmospheric pressure.
t_2 = the temperature of the saturated steam on the boiler side, corresponding to H_2.
t_1 = the temperature of the saturated steam on the atmospheric side, corresponding to H_1.
T = the temperature of the superheated steam on the atmospheric side, *i.e.*, the reading by the bottom thermometer, corrected.
$(T - t_1)$ = therefore, the degree of superheat on the atmospheric side.
L_2 = the latent of the saturated steam on the boiler side, corresponding to H_2.
K = the specific heat of superheated steam hitherto taken = ·48 at all pressures and degrees of superheat.

Another formula given by Professor Peabody himself takes into account the correction of the instrument, using two or more instruments and a separator, but is essentially the same as the above in principle.

The above formula may be used still, but the value of K must be the value of the Table XII., for the average value of K at atmospheric pressure from saturation to the degree of superheat required.

Another Formula Independent of K and of the Barometer Pressure.—If the superheat $(T - t_1)$ is above 16° F. we may substitute the value of K obtained in equation (11).

$$K_S^O = ·305 + \frac{5·00}{(T - t_1)} \qquad (11)$$

Also $(H_2 - H_1) = ·305\,(t_2 - t_1)$.
Substituting these values we have

$$w = 100 \times \frac{·305\,(t_2 - t_1) - ·305\,(T - t_1) - 5·00}{L_2}$$

$$\text{therefore } w = 100 \times \frac{·305\,(t_2 - T) - 5·00}{L_2} \qquad (17)$$

Here then $(t_2 - T)$ is simply the difference between the two thermometer readings on the calorimeter, which is all we require, and the formula needs no value for K_S^O nor for the pressure in the lower chamber. This holds so long as the superheat is above 16° F., which it usually is, unless the steam is very wet, and if the superheat $(T - t_1)$ is 10° F. the error is only 0·008 per cent. of wetness.

No barometer pressure reading is necessary, and it is therefore independent of the altitude as well as of K.

Radiation Correction for the Calorimeter.—The radiation correction must be determined by a separate experiment before the real test for wetness begins.

Once determined, it will always hold good for that instrument, if the lagging is kept the same and the boiler pressure roughly the same.

The best method is to insert the throttle disc or nipple on the boiler side of both thermometers. The steam will then be superheated round both thermometers, and the constant difference between their temperatures is the radiation correction to be applied.

The correction will take some time to determine, and the steam should blow through for two hours, unless the wetness and boiler pressure are remarkably constant.

Formulæ including Radiation Correction.—Let R^0 = the radiation correction, either in degrees C. or degrees F., according to the scale used.

The lower temperature must have at least 16° F. superheat while determining this radiation correction R. Then the loss by radiation in heat units = ·305 R.

Equation (16) will then become

$$w = 100 \times \frac{H_2 - H_1 - K^0_{(S} (T - t_1) - \cdot 305\, R}{L_2} \quad (18)$$

It will not do to simply add R^0 to T as a thermometer correction.

Equation (17) becomes

$$w = 100 \times \frac{\cdot 305\,(t_2 - T - R) - 5\cdot 00}{L_2} \quad (19)$$

Summary of Equations for Throttling Calorimeter, without radiation correction.

$$w = 100 + \frac{H_2 - H_1 - K^0_S (T - t_1)}{L_2} \quad (16)$$

[K^0_S taken from Table XII. Used for all degrees of superheat in chamber.]

$$\text{and } w = 100 \times \frac{\cdot 305\,(t_2 - T) - 5\cdot 00}{L_2} \quad (17)$$

[Independent of K and of the barometer pressure, but degrees of superheat must be above 16° F.]

Error using this formula at 10° F. superheat = 0·008 per cent. wetness or moisture.

With radiation correction of R^0

$$w = 100 \times \frac{H_2 - H_1 - K^0_S (T - t_1) - \cdot 305\, R}{L_2} \quad (18)$$

[K^0_S taken from Table XII. Used for all degrees of superheat in chamber.]

$$\text{and } w = 100 \times \frac{\cdot 305\,(t_2 - T - R) - 5\cdot 00}{L_2} \quad (19)$$

[Independent of K and of the barometer pressure, but degrees of superheat must be above 16° F.]

Error using this formula at 10° F. superheat = 0·008 per cent. wetness or moisture.

Equations (16) and (17) or (18) and (19), if a radiation correction is applied, give the same results.

For (16) and (18) K^0_S is taken from Table XII.

For (17) and (19) the limits of pressure in the chamber are about from 12 to 16 lbs. per sq. in. This variation in pressure, due to altitude or a changing barometer pressure, will cause no sensible error in the values of K or of the results deduced.

Is Superheated Steam a Perfect Gas?

The "Joule - Thomson" Experiments.—These superheated steam experiments are the same in principle as the porous plug experiment, carried out by Joule and Thomson (Lord Kelvin) some fifty years ago, to determine the absolute zero on the thermo-dynamic scale, the permanent gases being used as their working substance; and also to prove the result of Joule's previous experiment, that when a gas expands freely the cooling due to expansion is balanced by the work done due to the change of volume, and consequently the temperature remains constant or as Joule put it: No change of temperature occurs when air is allowed to expand in such a manner as not to develop mechanical power.

The only difference is that in the Joule-Thomson experiments the temperature was measured on each side of the porous plug, as in the radiation experiments above for Table XV. This was quite convenient as the gases used were at atmospheric temperature and so there was no or very little radiation correction.

Also it was not necessary to determine the saturation pressure and temperature, which in the above superheated steam experiments is as important as the rise or fall of temperature.

Still the principle is the same.

The results of these experiments from Lord Kelvin's article on "Heat" are—

Name of Gas.	Proper Mean Cooling Effect, per Atmosphere in deg. C.
Hydrogen	— 0·039 °C.
Air	+ 0·208 °C.
Carbon Dioxide ...	+ 1·005 °C.

The experiments on air were taken as the most accurate.

Maximum Deviation of Superheated Steam from Joule's Law.—Now assuming a maximum error of one-tenth of a division of the thermometer used in the superheated steam tests on no variation, Tables I. to IV., the cooling effect due to this maximum error would be—

TABLE XVI.

Name of Gas.	Test No.	Largest Error of Observation in deg. C.	Cooling Effect of such Error per atmosphere in deg. C.
Superheated Steam, with more than 40 deg. F. Superheat.	6	0·01 °C.	0·02 °C.
	20	0·10 °C.	0·03 °C.
	24	0·10 °C.	0·016 °C.
	26	0·01 °C.	0·01 °C.

The smallest of these cooling errors, for superheated steam, is no less than four times smaller than Lord Kelvin's cooling effect for hydrogen and twenty times smaller than that for air.

Professor Thomas Preston on Perfect Gases.—According to Preston, in his "Theory of Heat," p. 802, where the whole of the Joule-Thomson porous plug experiment is most lucidly described, any cooling effect may be due to two causes, the molecular attractions in the gas or to the cooling effect $p^1v^1 - pv$ produced by external work, in consequence of deviations from Boyle's law.

Also, he says, "on the other hand, the cooling effect arising from expansion under molecular forces will be diminished by the heating arising from decrease of pv under decreased pressure in the case of hydrogen and substances in a similar state."

It is then possible for a gas to deviate from Boyle's law, as hydrogen does, and yet have molecular forces in operation, so that there is no cooling or heating effect in the above experiments, because the two are exactly balanced, and therefore we cannot say that it is a perfect gas, even though there is absolutely no cooling effect whatever, that is, even if the gas obeys Joule's law perfectly.

This is certainly not in accord with Clerk Maxwell, where he implies that if a gas obeys Joule's law perfectly, then it is a perfect gas. (See his "Theory of Heat," p. 216.)

Again, since there is no variation in the temperature for superheated steam, under very different pressures and temperatures, it is highly improbable that the molecular forces always exactly balance the effect due to the deviation from Boyle's law, though it is possible.

Till it is proved to the contrary, therefore, we may infer that no molecular attractions exist, after 16° F. superheat at atmospheric pressure, and after 3·5° F. superheat at 150 lb. per sq. in. pressure for superheated steam, and therefore since there is no variation in the temperature in the above experiments, in which the maximum error is less than the variation for hydrogen obtained in the Joule-Thomson experiments, it follows that superheated steam is the most perfect gas known.

But whether we accept this or reject it is of no consequence to the theory of equation (8) for determining K. For by definition the heat required to overcome the molecular forces, or to be added or subtracted according to deviation from Boyle's law is included in the value of K.

Regnault's Value for $\frac{dH}{d\theta}$.—The figures on which the value of K does entirely depend are the results of Regnault's determinations of the total heat of saturated steam.

Regnault's equation that the total heat varies as ·305 times the temperature is accepted universally as being the best, and Regnault made more experiments for this particular figure than for any other single constant.

Principal Griffiths has obtained, instead of ·305, the value ·399. Whichever value is the correct one, must be the real specific heat of superheated steam for that particular pressure.

All Data Figures are as Registered during the Experiments.—The figures in the tables are given exactly as registered during the experiments.

The values of K are deduced direct from these figures by the equations given and using Regnault's figure for $\frac{dH}{d\theta} = ·305$, and

any one may plot the curves $A\,A$ and $B\,B$ from the values so obtained to any size of scale they may choose.

Likewise the figures in Tables XII. and XIII. are calculated direct from their respective formulæ.

A New Value for $\frac{dH}{d\theta}$ *will not nullify these Experiments.*—So if some fresh and more exact experiments on saturated steam, re-determine the constant $\frac{dH}{d\theta}$ (*i.e.*, ·305 as obtained by Regnault) it will be no great effort to recalculate the corresponding new values of K in all the tables.

Other Vapours.

If the value of $\frac{dH}{d\theta}$ for a saturated vapour is a constant (in the case of steam $\frac{dH}{d\theta} = ·305$) then if the vapour is superheated high enough, so as to become a perfect gas (and all vapours approach perfection, the more they are superheated), the value of its specific heat at constant pressure in the superheated state is the constant $\frac{dH}{d\theta}$ for its saturated condition.

How does this apply to vapours other than steam whose specific heats and values for $\frac{dH}{d\theta}$ have been separately determined?

The following figures are taken from Preston's "Theory of Heat," and Peabody's "Tables of Saturated Steam and other Vapours." All the experiments were carried out by Regnault.

Specific Heats of Superheated Vapours under constant pressure (Regnault)—

Vapour.	K.
Ether	0·47966
Bisulphide of Carbon ..	0·15696
Chloroform	0·15666
Acetone	0·41246
Water	0·4805

The superheated vapour was in all cases condensed to liquid, and so the value of the specific heats, K, is the average value from saturation upwards.

It may therefore be expected to be rather larger than $\frac{dH}{d\theta}$ for the same vapour saturated.

Formulæ for the Total Heat of Saturated Vapours (Regnault).

Ether, $H = 94 + 0·45t - ·00055556t^2$
Bisulphide of Carbon, $H = 90 + 0·14601t - ·0004123t^2$
Chloroform, $H = 67 + 0·1375t$
Acetone, $H = 140·5 + 0·36644t - ·000516t^2$
Water, $H = 606·5 + 0·305t$
Hence we have—

TABLE XVII.

Vapour.	$\frac{dH}{d\theta}$ Approximately.	Specific Heat K_T^0	Difference.
Ether	0·45	0·47966	0·02966
Bisulphide of Carbon	0·14601	0·15696	0·01095
Chloroform	0·1375	0·15666	0·01916
Acetone	0·36644	0·41246	0·04602
Water	0·305	0·4805	0·1755

As will be seen, water has by far the largest difference, and the determination of its specific heat as a superheated vapour involves the most difficulty.

The other vapours show a very small difference, which may be accounted for by the determination of the specific heat, at and near the saturation point of the vapour, as the vapour was made to condense during the experiment.

So from Regnault's own results on superheated vapours, other than steam, there seems every likelihood of his values for $\frac{dH}{d\theta}$ and the specific heat under constant pressure being of the same value for each vapour, if the vapour is sufficiently superheated, to behave as a perfect gas and obey Joule's law.

Appendix.

The whole of the above sections was written about eight months ago. Since then I have become aware of the experiments of Grindley, Griezmann and Calander in the year 1900. They have carried out their experiments on the alternative method already described. Passing exactly dry saturated steam through the throttling disc, and by measuring the temperature on both sides of the disc, they obtain a value for K at different temperatures and pressures. In all cases this, then, is the average value of K from saturation to the degree of superheat used. The difficulties of this method have already

been pointed out, but they will be better realised by reading Grindley's paper ("Philosophical Transactions," 1900). The elaborate precautions necessary in all the experiments and the designs of the apparatus, show to what extent that experimenter had to go in order to obtain his figures.

He summarises his results thus: (1) that the steam never becomes a perfect gas, however much he lowers the pressure in the lower chamber; (2) that the points of greatest interest are the most difficult to obtain; (3) that the average value of K varies largely with the temperature, but its value is practically independent of the pressure.

The only point at serious variance between his results and mine is No. (1), and I can only account for this by the difficulties of this alternative method and the fact that high degrees of superheat could not be or were not employed.

On the other hand, Grindley finds large variation in the average value of K for different temperatures, and this is certainly the case, especially near saturation (see Tables XII. and XIII.). He finds it does not vary much for pressure, and over small pressures this is the case.

He also had to contend with a large radiation factor, so that the high result for radiation already described only bears out what Grindley had already found.

Griezmann and Calander's experiments were carried out on similar lines to Grindley's, always using this alternative method of two thermometers with dry saturated steam, so the values obtained are the average values of K in all cases.

It will be noted that all the various determinations of K by different experimenters both at home and abroad are all included in the Tables XII. and XIII., and that because the various values do not agree, that is no sign that the experimenter was in error, for the average value is a very variable quantity near saturation.

The fact that the rate of flow of saturated steam through an orifice does not vary for a change of pressure on the lower side, so long as the low pressure is not more than 58 per cent. of the high pressure, was experimentally proved by D. K. Clarke (see his "Steam Engine"). As this fact might not hold for superheated vapours, the experiment was carried out with oxygen. Compressed oxygen from a cylinder at about 35 atmos. was allowed to flow through a valve opened very slightly into the bomb of a "Mahler" calorimeter. Readings were taken of the rise of pressure in the bomb, and the time noted with a stop watch to the fifth part of a second for every increase of 10 lbs. per sq. in. in pressure. The pressure in the cylinder fell about half an atmos., while that in the bomb rose from 0 to 180 lbs. per sq. in. and the rate of increase of this pressure was quite constant from the start to the finish of the experiment. This proved conclusively that varying the pressure on the lower side does not vary the rate of flow through the orifice. In all the experiments on the superheated steam the boiler pressure was kept more than double the lower, to insure a constant flow.

This law does not apply if the low pressure remains constant (say, atmospheric) and the high pressure is allowed to diminish till it reaches that of the atmosphere. That is, the rate of flow of gas through an orifice will vary if the high pressure varies, but will remain constant if the high pressure is kept constant, even though the low pressure is varied, provided the low pressure is not more than 58 per cent. of the high pressure (using Clarke's figure for saturated steam).

All the experimental work was carried out with the greatest care, and I can certainly vouch for the accuracy of the data given in the Tables I. to XI. The duplicate results and all the readings are also given just as recorded, so that the experimental error is seen at a glance.

It is true that the experiments do not establish an independent value of the specific heat of superheated steam. What they really do is to give the exact relation of the specific heat to the formula for the total heat of saturated steam.

And it is true that if a different formula than that of Regnault's for saturated steam is used then the values of K will differ accordingly.

But since all the tables on saturated steam are based on Regnault's formula for the total heat (Peabody's, Porter's, Clarke's and all in universal use are based on his equation), then if we, as engineers, continue to use Regnault's results for saturated steam, the results which we have now used for fifty years, we must most certainly use those values of K. given in Tables XII. and XIII., which are calculated in relation to Regnault's formula from the experimental data given in Tables I. to XI.

But further experiments should be conducted to determine the exact rate of change of the quantity Υ over a large range of pressures.

Υ has only been determined for the atmospheric pressure (12 lb. per sq. in. at the Johannesburg altitude) and for 150 lb. per sq. in., and its values are respectively

5·00 and ·46. And since steam still obeys accurately Joule's law for large changes of pressure, for which changes of pressure **Y** must very materially alter, it follows that Regnault's linear law for the total heat of saturated steam cannot be exactly right. For if the linear law is correct, **Y** must necessarily be a constant quantity, because Joule's law is obeyed over large ranges of pressure (see Tables II., III., and IV.).

Since the value of **Y** could be accurately determined for all pressures, in the same way as it has been done for atmospheric pressure and 150 lb. per sq. in., the exact law for the variation of **Y** can be experimentally determined.

So the problem stands thus: Given the rate of variation of **Y**, what is the form of the equation for the saturated steam, and, if possible, what is the ratio of the constants in that equation?

Once this form of equation is fixed, it only remains to measure the total heat at one and the most convenient pressure, and this gives us the constants to complete the equation. It is not necessary to conduct a vast series of experiments, as Regnault did, to determine this equation. It need only be done for one, or perhaps two, pressures, and the rest at once follows from the law of the variation of **Y**.

This seems to me far the most accurate way of measuring the properties of saturated and superheated steam.

Will any of our mathematicians or mathematical physicists solve the problem, using symbols where constants are necessary: "If the rate of change of the quantity **Y** follows a linear law or any higher law, what is the equation for the total heat of the saturated steam, assuming Joule's law to be followed over large ranges of pressures?"

Motor Engineering.

By R. E. PHILLIPS, M.I.Mech.E., A.M.Inst.C.E.

THE PARIS MOTOR SHOW.

The most that can be said of this exhibition is that it surpassed every previous show either in Paris or elsewhere in the gorgeousness of the settings of the exhibits and the brilliancy of the illuminations. Taken as a whole, the exhibits—like those at Olympia—show nothing of a startling nature, nor any very striking departure from accepted practice, although throughout the exhibition there are many novelties in details of construction that are deserving of the closest attention, as they indicate that the hand of the designer still finds play in the perfection of the mechanism of the modern motor car. In the brief space at our disposal we shall therefore only deal with such departures from accepted practice.

In the "Aguila" car, which is an Italian production, the whole of the six cylinders of the engine are in one casting which is carrying the unit principle to a greater length in this direction than has been done before. In the "Vulpes" engine the lower half of the crank chamber, the fly wheel pit, and the lower half of the gear box are all formed in one piece, while in the "Bayard" engine the four cylinders with their valve boxes and the upper part of the crank chamber are in one casting. In the "Hispano" engine—a Spanish production—the crank-chamber and gear box are joined up to form one rigid member, the lower halves of each being bolted together under the fly wheel. In the engine of the "Germain" car, a Belgian production, the crank shaft is formed with discs of large diameter between the cranks, the peripheries of the discs forming races for single row ball bearings of an unusually large diameter which prevent "whip" in the crank shaft and materially shorten the total length of the said shaft, thus enabling the cylinders to be kept closer together. In the Swiss built car, the "Helios," the clutch operating mechanism and the universal joint behind the clutch are enclosed in a separate case.

As in the leading British cars exhibited at Olympia, special attention has been given by French manufacturers to the question of lubrication, the force feed system by means of a direct acting pump being largely employed. On the "Bolide" car the fan, which is surrounded by a water tank, has its blades constructed of a series of small tubes through which the water circulates. The "Leon Bollee" carburettor is still fitted with two jets, but instead of being alternative, they are now supplemental, being so coupled up to the control device that either one or both can be brought into action as desired. The "Motobloc" car is fitted with a novel arrangement to prevent the petrol, which is pressure fed by the exhaust, from being delivered to the carburettor at excessive pressure. On the dashboard is a small tank which supplies the carburettor direct by gravity until the exhaust provides the necessary pressure. This tank is also fitted with a float feed similar to a carburettor, the function of which is to ensure that the pressure of the petrol feed to the carburettor shall not exceed the normal, as the moment it does so the float rises and cuts off the supply.

In the new Italian "Esperia" car the clutch, which is of the multiple disc type, is placed in the gear box, which arrangement we presume requires that the oil used in the gear box is of a kind suitable for the clutch. The clutch employed on the "Parant" car consists of an annular disc carried by the flywheel and two pairs of dogs carried by radial arms mounted on the shaft, the latter being brought into gripping engagement with the annular disc by means of toggle levers. In the gear of the "Minerva" car the second speed wheel has internal as well as external teeth, thus enabling it to be locked to its shaft by meshing with its internal teeth the small forward wheel on the shaft which enables the size of the gear box to be materially reduced. In the "Standard" car, another Italian production, the short shaft which drives the live axle from the cardan shaft is carried right through the differential casing, so that it is supported at both ends. The differential gear is mounted on this shaft and is provided with two bevel pinions, each meshing with a bevel crown wheel mounted on the ends of the two parts of the live axle. The advantages claimed for this construction are, that it permits of the driving wheels being splayed, that it prevents any sag in the axle, and that it

allows each part of the axle to alter its position with respect to the other within certain limits, without throwing any strain on the pinions of the differential.

The "F. I. A. T." car is provided with a differential gear immediately behind the gear box and two cardan shafts are employed to drive the two parts of the live axle, an exceedingly clever arrangement being employed to obtain the necessary universal joint. These shafts are carried in oil-tight tubular cases and drive the two parts of the live axle by bevel gearing. The cardan shaft employed in the "Gillet-Forest" car instead of running from the live axle direct to the gear box is supported in a bearing located a short distance from the back end of the gear box. In the "Esperia" car the radius rod from the live axle takes the form of a tubular casing enclosing the cardan shaft. The front end of this casing is anchored to the gear-box by a link, the hinge of which is concentric with the axis of the universal joint of the cardan shaft, while to the link are attached two tie-rods which run to a transverse member of the frame. The drive from the road wheels is thus transmitted through the cardan shaft to the link and from the link through the tie-rods to the frame. By this construction the weight of the casing is taken off the cardan shaft, and the radius rods are in tension instead of in compression.

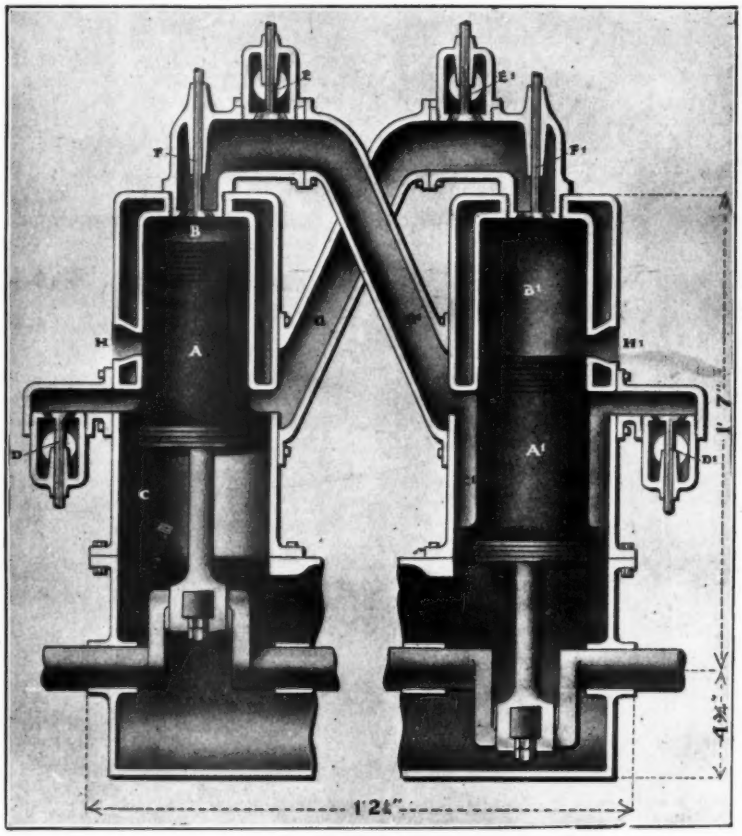
On the "Klob" car a new system of spring suspension is employed. The rear springs, instead of being attached to the axle in the usual way, are mounted centrally upon girder plates, one on each side, and jointed freely to the axle at the rear ends, the other ends being supported on spiral springs carried on studs depending from the side members of the frame. This arrangement gives a longer wheel base to a short frame. The frame of the "Tourand and Charmion" chassis, which is of pressed steel, instead of being of the usual channel section, is made of angular section at the bottom, but the top edge is bent over to form a tubular section, and is then rivetted to the vertical side. The "Westinghouse" cars, which performed so well in the recent "Concours de Regularité" in France, were conspicuous by reason of fine workmanship rather than by novelty in details of construction. In the chassis of the 4-cylinder "Motobloc" the cylinders are arranged in pairs with the flywheel mounted between them. The gear-box is in one with the crank chamber, so that both the flywheel and the clutch are enclosed. In the engine of the "Niclausse" car the main feed water pipe is cast in the crank chamber, thus reducing the amount of piping and rendering the valves more accessible.

The Antoinette Company, besides showing a 24-cylinder engine — for motor-boat work, exhibited a light car with a novel form of transmission, having neither a clutch, change speed gear, or differential gear. Behind the engine is a small box, which contains a pair of pinions and bevel gear for giving a forward and reverse drive to the countershaft, on each end of which is a drum filled with oil, containing a large and small pinion, which forms a pair of oil couplings on the shaft. A skew gear actuates these oil couplings in such a manner as to wholly or partially lock one of the driving wheels, according to the amount of turning movement given to the steering wheels. There is also an independent control of the mechanism by a lever, which takes the place of the usual change speed lever, so as to enable the countershaft to be locked so as to revolve solid. The frame of the "Alcyon" voiturette is novel, inasmuch as part of the sides of the body are made in one with it, forming also the platform for the seat.

Heavy Vehicles.

In the heavy vehicle section, the most interesting exhibits were the new "Darracq-Serpollet" omnibus chassis, the new six-wheeled chassis of M. Brillié, and the "Purrey" steam lorry. The "Darracq-Serpollet" chassis is fitted with a 30—40 h.-p. engine, having two double-acting high-pressure cylinders of 90 millimetres bore and 125 millimetres stroke. The exhaust steam passes into two sets of superheating pipes arranged in groups parallel with and slightly below the casing of the engine. After passing round the feed water pipes, the exhaust steam flows into a condenser and thence into a radiator located at the front of the chassis. The fuel, water and lubrication, are automatically controlled by a single steam pump, which actuates two pumps for the fuel and water respectively, while motion is taken from the connections of one of the pumps to control the delivery of the lubricating oil for a mechanical lubricator. Transmission to the road wheels is by means of roller chains. In the six-wheeled "Brillié" chassis both the front and rear pairs of wheels are dirigible on the "Akerman" principle. Compensating levers of the locomotive type are introduced between the springs carrying the central and rear axles, and the latter axle is stayed at the rear to a cross member of the frame at two

points. In the "Purrey" steam wagon a horizontal compound engine, a water tube boiler, and a single gear ratio are employed. On each end of the crank shaft is a steel pinion, which gears with spur wheels on the differential shaft which is located immediately behind the engine. From the differential shaft the transmission is by means of sprocket wheels and chains. In tyres, the only interesting novelty is the "Bergougnan" solid tyre for heavy vehicles. This is of crescent section of soft rubber, with a hard vulcanite base, in which is a steel band, the outer surface of which has longitudinally arranged grooves of dove tail section. The vulcanite under the steel band acts as a cushion between it and a metal rim fixed to the felloe of the wheel. Both this rim and the inner face of the tyre are turned. The tyre is pressed on to the rim, and is held thereon by a ring fixed to the rim by radially arranged screws. These tyres are largely used by the Paris Omnibus Co. and give every satisfaction, as the manufacturers guarantee a minimum of 20,000 kilometres per tyre.



THE BRITISH DUPLEX MOTOR.

THE BRITISH DUPLEX MOTOR.

Through the courtesy of the Motor Engine and Manufacturing Co., Ltd., the writer had

the opportunity of seeing this motor running. Without any load the engine ran at any speed from 250 to about 1,200 revolutions per minute, and it is stated that it has been run at 1,500 revolutions per minute. Up to the present no reliable brake tests have been made, but we understand that these will be undertaken at once, and we hope at an early date to be able to place the results before our readers, as this two-cycle engine appears to give greater promise than any other previous attempt. The construction of the motor will be easily understood from the diagrammatic illustration, which shows all the important features with the exception of the supplemental exhaust ports, which are arranged to give the main exhaust a lead of about half an inch. It will be seen that each cylinder contains two chambers of unequal diameters. It is in the upper ones B, B_1, that the expansion of the exploded gases takes place, and they are, therefore, water-cooled. The lower chambers C, C_1, are the larger in diameter, and have uncooled walls. Trunk pistons A, A_1, with their lower ends enlarged, separate the two chambers of each cylinder, three piston rings on the upper end and two on the lower ensuring the necessary tightness. The cranks are set 180 degrees apart, one piston thus being on its up stroke whilst the other is on its down stroke. Assuming the cranks to be in the position shown in the diagram, the cycle of operations will take place in the following sequence, as the engine is started up. In No. 1 cylinder (the left one in the illustration) as the piston A descends it will open both the air valve E_1 which communicates with the lower chamber C through the transfer pipe G, and also the mixture valve D. The valve F_1 will be held closed both by the suction from the piston A and by the compression from the upward moving piston A_1 in No. 2 cylinder. A rich mixture is then drawn from the carburettor through the valve D into the chamber C, whilst at the same time pure air is sucked in through the valve E_1 and the pipe G. When the piston A commences its up stroke both the valves E and D close, and both the mixture in the chamber C and the air in the pipe G are compressed. An operation similar to that just completed in the lower chamber of No. 1 cylinder will now commence in the lower chamber of No. 2 cylinder, the piston of said cylinder being on a down stroke. Directly this pressure can overcome the decreasing compression in the working chamber B_1 of No. 2 cylinder, the valve F_1 will open, admitting under pressure first the cushion of pure air from the pipe G which thoroughly scavenges the cylinder and passes out through the exhaust port H_1, and then the rich mixture from the chamber C which can enter only after the pure air above it in the pipe has been displaced. As piston A_1 ascends, and until it has covered both the main exhaust port H_1, and also the supplemental exhaust ports, leakage will take place from the chamber B_1, but the lower portion of this space being filled only with pure air no fuel is wasted. As soon as the exhaust ports are covered by the piston, the mixture in the chamber B_1 will be compressed, whilst in No. 1 cylinder the chamber C will again be sucking in air and mixture, and the chamber B be scavenged by the air from the transfer pipe G_1 communicating with the lower chamber of No. 2 cylinder. When the piston A_1 has commenced its down stroke, the compressed mixture in the chamber B_1 is fired, and the motor commences to work. Meanwhile the air scavenging in No. 1 cylinder having been completed, the mixture pumped in, and the exhaust port covered, compression takes place, so that No. 1 cylinder fires just after the working stroke in No. 2 cylinder is completed. Alternate firing on every stroke will then be maintained by the pumps feeding one or other of the working cylinders on every stroke.

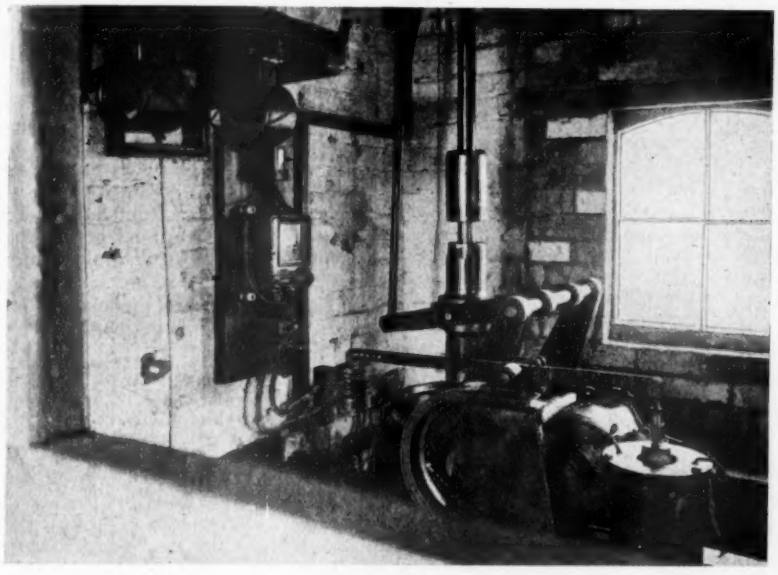
Railway Engineering Notes.

Electrically worked Level Crossing Gates at Waterloo.

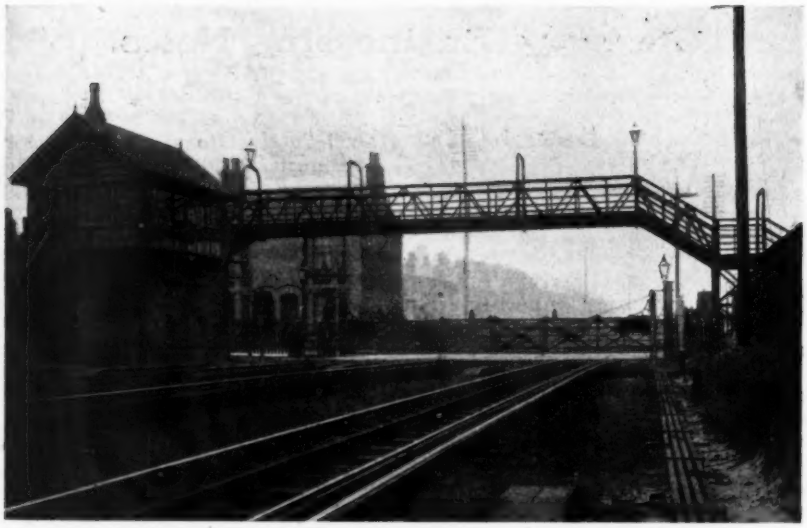
The Lancashire and Yorkshire Railway have recently put into operation a novel installation in the shape of level crossing gates to which electrical working has been applied. They are situated at Waterloo, near Liverpool, and a view of them is given in the accompanying illustration. The motor employed is one of 2 h.-p., running at 1,500 revolutions per minute, and the movement of the gates is accomplished in about fifteen seconds. The motor is double wound, so that the action may be reversed for opening and closing the gates respectively. A lever, the normal position of which is midway in the frame, is provided to operate the electrical switches, and a forward movement of this lever applies current to operate the motor in one direction, and the reverse movement of the lever applies current for the opposite direction. In addition to the switches worked by this lever there is a graduated switch worked by hand, provided so that the signalman may regulate the speed of the motor as the gates are worked. When the movement of the gates is completed in either direction the current is cut off automatically by means of switches worked off the gate shaft.

The switch lever in the frame is interlocked with the gate bolt and stops in the usual way, so that the power cannot be applied unless the signals are on, nor until the gates have been unbolted.

A clutch is provided, worked by a separate lever, by means of which the



ELECTRICALLY WORKED LEVEL CROSSING GATES VIEW OF APPARATUS.



ELECTRICALLY OPERATED GATES AT WATERLOO, NEAR LIVERPOOL, L. & Y. RAILWAY.

gate gearing can be connected to the ordinary gate wheel in case of the power failing. The motor is connected to the gate driving gear by means of a friction clutch, the object of this being to prevent the motor and gear being damaged in the event of the gates encountering any obstruction. The friction gearing can be regulated as required. The level crossing is a busy one, and the traffic upon the railway is heavy. It is anticipated that the average consumption of the current per day will amount to not more than 2 B. T. U. We are indebted to Mr. C. B. Byles, signal engineer of the railway for the photographs and details.

Eight Wheels Coupled Goods Engine No. 20, G.E. Railway.

Three years ago the process of development of the tank locomotive for heavy suburban traffic reached an interesting stage when Mr. Holden, M.Inst.C.E., Locomotive Superintendent of the Great Eastern Railway, constructed a locomotive of unusual design, known as a "Decapod," having a 0-10-0 wheel arrangement, "Wootten" firebox and three cylinders, all working simple expansion. This engine, which was described and illustrated in THE ENGINEERING REVIEW at the time of its completion, was destined never to fulfil its intended function of hauling the heavy suburban traffic on the Enfield branch of the G.E.R., but was, we believe, utilised at Stratford works, where it has recently been reconstructed to emerge as an eight wheels coupled goods engine, forming the subject of the accompanying illustration.

The following are the leading dimensions of this interesting engine :—

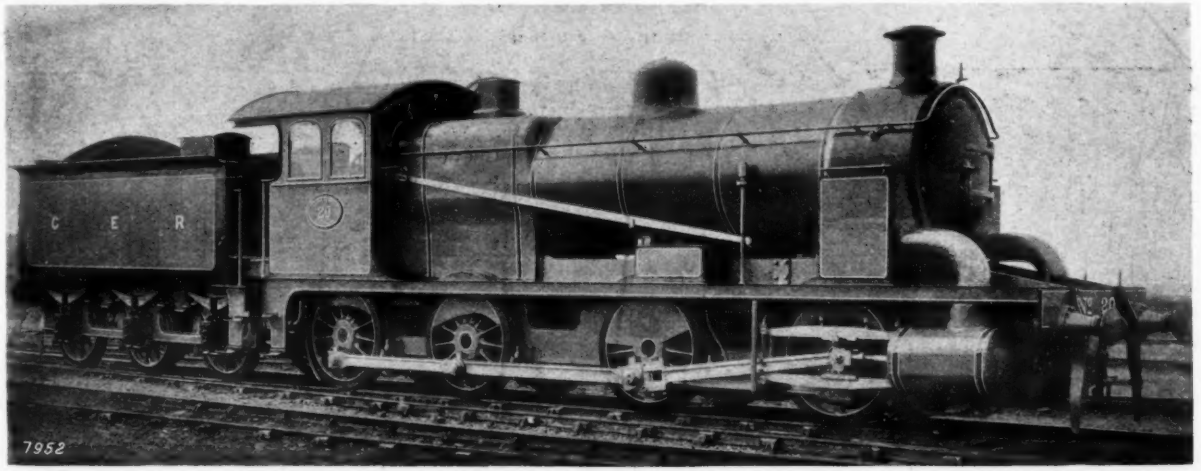
Two cylinders (outside) 18½ ins. by 24 ins. stroke (horizontal).	
Boiler (outside diameter), 4 ft. 9 ins.	
Length of barrel, 12 ft. 11⅛ ins.	
Between tube plates, 13 ft. 3⅛ ins.	
Number of tubes, 285; 1¾ ins. outside diameter.	
Length outside firebox (Belpaire), 8 ft.	
Width " " "	3 ft. 9⅜ ins.
Grate area, 229 sq. ft.	
Heating surface of tubes,	1,738·2 sq. ft.
" " " firebox	131·4 " "
Total	1,869·6

Boiler pressure, 180 lbs. per sq. in.
Boiler centre from rail, 8 ft. 3 ins.
Diameter of wheels, 4 ft. 6 ins.
Leading to driving, 7 ft. 6 ins.
Driving to intermediate, 8 ft. 9 ins.
Intermediate to trailing, 7 ft.
Total wheelbase of engine, 23 ft. 3 ins.
Leading :—Weights : empty, 14 tons, 5 cwts., 2 qrs. ; loaded, 15 tons, 14 cwts., 3 qrs.
Driving :—Weights : empty, 15 tons, 17 cwts., 3 qrs. ; loaded, 16 tons, 14 cwts.
Intermediate :—Weights : empty, 11 tons, 7 cwts., 3 qrs. ; loaded, 12 tons, 4 cwts.
Trailing :—Weights : empty, 8 tons, 13 cwts., 1 qr. ; loaded, 9 tons, 14 cwts.
Total weight of engine, empty, 50 tons, 4 cwts., 1 qr.
Total weight of engine, loaded, 54 tons, 6 cwts. 3 qrs.

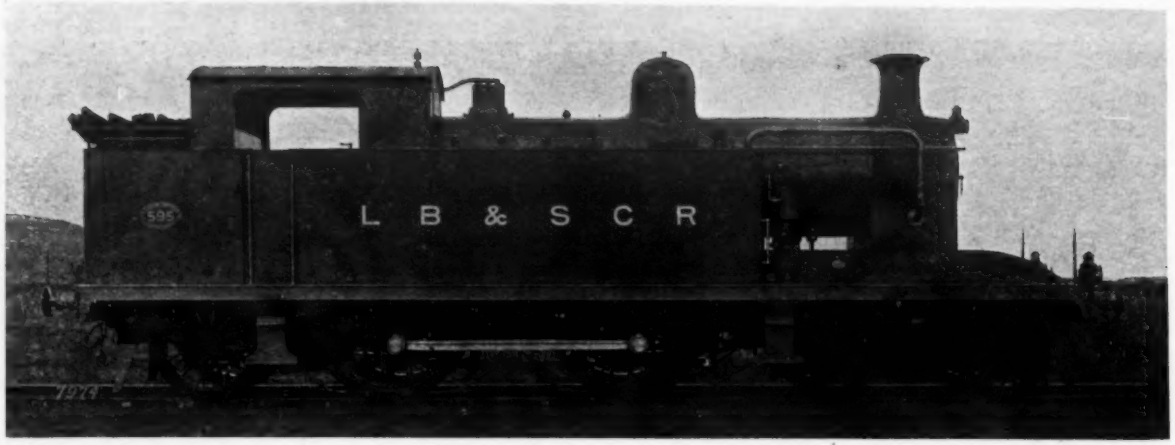
Stephenson's link motion.
Length of connecting rod, 8 ft. $2\frac{3}{8}$ ins. centres.
Eccentrics, $5\frac{3}{4}$ ins. throw.
Angular advance, $104\frac{1}{2}$ deg.
Frames, $1\frac{1}{2}$ ins. thick.
Distance between, 3 ft. $10\frac{3}{4}$ ins.
Total length, 34 ft. 4 ins.
Steam brake. Leading and trailing axleboxes of radial type.
Tractive force, 22451 lbs.
Adhesive weight, 27,603 lbs.

TENDER.

Six wheels, 4 ft. 1 in. diameter.
Wheelbase, 12 ft diameter.
Weights, empty :—leading : 5 tons, 5 cwts., 3 qrs. ; centre : 6 tons, 13 cwts., 1 qr. ; trailing : 5 tons, 12 cwts., 3 qrs.



THE CONVERTED "DECAPOD," G.E. RAILWAY.



4-4-2 TYPE TANK LOCOMOTIVE, L.B. & S.C. RAILWAY.

Weights, loaded:—leading: 11 tons, 18 cwts., 3 qrs.; centre: 12 tons, 17 cwts., 1 qr.; trailing, 13 tons, 9 cwts.
Total weight—empty, 17 tons, 11 cwts., 3 qrs.
" " loaded, 38 tons, 5 cwts.
" " of engine and tender, empty, 67 tons, 16 cwts.
" " of engine and tender, loaded, 92 tons, 11 cwts., 3 qrs.
Total wheelbase of engine and tender, 42 ft. 10 ins.
Total length over buffers, 56 ft. 11 ins.
Capacity of tanks, 3,500 gallons.
Coal, 5 tons.

4-4-2 Type Tank Locomotive, L.B. & S.C. Railway.

A new series of large size tank locomotives is now under construction at the Brighton works of the L.B. & S.C. Railway Company, the first of which has recently been completed and is illustrated in the accompanying half-tone. The design is a particularly neat one, in spite of the fact that the engine is fitted with condensing apparatus, and a consideration of the dimensions shows that it is well adapted for hauling heavy suburban and long distance slow traffic for which it is intended. It provides another instance of the growing popularity and unquestionable utility of the heavy type tank locomotive which on the Great Western, London and North Western and Great Central are accomplishing remarkable performances.

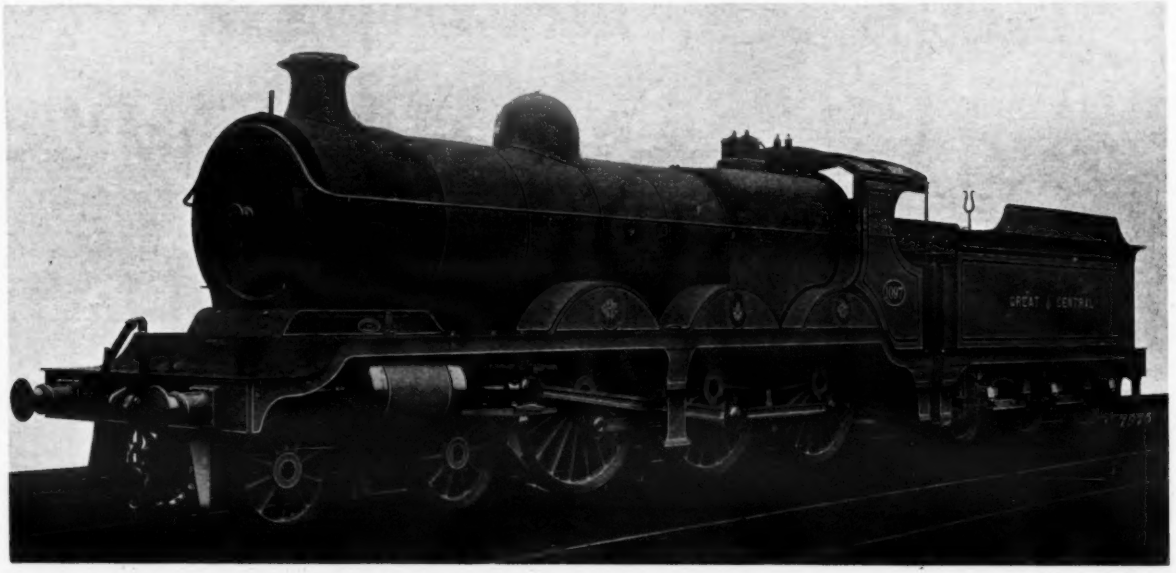
We are indebted to the designer, Mr. Earle Marsh, for the photograph and the following leading particulars of the engine:—

Cylinders:	diameter	17½ ins.
,,	piston stroke	26 ins.
Bogie wheels:	diameter	3 ft. 6 ins.

Coupled wheels diameter	5 ft. 6 ins.
Trailing wheels : diameter	4 ft.
Wheelbase : coupled	8 ft. 9 ins.
,, total	28 ft. 11¼ ins.
Boiler : diameter (outside)	4 ft. 3 ins.
,, length	10 ft. 10¼ ins.
Heating surface : tubes	947·63 sq. ft.
,, ,, firebox	93·25 sq. ft.
Grate area	17·43 sq. ft.
Working pressure	170 lbs. per sq. in.
Weight on coupled wheels	36 tons, 12 cwts.
Weight of engine in working order with 1,983 gallons of water and 3 tons, 5 cwts. of coal	68 tons, 5 cwts.
Tractive force	18,720 lbs.

4-6-0 Type Goods Engine Great Central Railway.

A new series of 4-6-0 type locomotives similar in general respects to the two classes having a similar wheel



4-6-0 TYPE FAST GOODS LOCOMOTIVE, GREAT CENTRAL RAILWAY.

arrangement already in use on this railway, have recently been delivered to the company by Messrs. Beyer, Peacock & Co. Ltd., of Gorton, who were responsible for their construction, the design, of course, being by Mr. J. G. Robinson, the locomotive superintendent of the line. These engines are intended for dealing with the heavy fish and long distance goods trains, and in the summer time for heavy excursion traffic. For this purpose the coupled wheels have a diameter on tread of 6 ft. 6 ins., thus placing them in an intermediate position between express passenger 4-6-0 type having coupled wheels of 6 ft. 9 ins. diameter and those having coupled wheels of 5 ft. 3 ins. diameter. The boiler, it will be noted, has the usual type of "Belpaire" firebox, the stays of which are enclosed in iron tubes carried above the water level, the interstices being filled with Portland cement. Steam is distributed to the outside cylinders through "Stephenson" link motion and balanced slide valves, the drive being on the intermediate coupled wheels. Water pick-up apparatus is fitted on the tender, the scoop being raised and depressed by means of a steam cylinder. The following are the leading particulars:—

Cylinders: diameter ...	19½ ins.
,, stroke	26 ins.
Coupled wheels: diameter...	6 ft. 6 ins.
Bogie wheels: diameter ...	3 ft. 6 ins.
Boiler: centre line from rail	8 ft. 6 ins.
,, mean outside diameter	4 ft. 10¾ ins.
,, length of barrel ...	15 ft.
Number of tubes	221
Diameter of tubes (outside)	2 ins.
Heating surface: tubes ...	1777·9 sq. ft.
,, ,, fire-box ...	133·1 sq. ft.
Total heating surface ...	1,911 sq. ft.
Grate area	26 sq. ft.
Working pressure	200 lbs.
Tender, diameter of wheels	4 ft. 3 ins.

Engine weights:

	tons.	cwt.	qr.
On bogie wheels ...	16	0	0
,, leading coupled wheels	18	6	0
,, driving ,, ,,	18	6	0
,, trailing ,, ,,	17	18	0
Total, in working order ...	70	10	0

Tender:

	tons.	cwt.	qr.
Weight on leading wheels	15	15	0
,, intermediate wheels ...	12	19	0
,, trailing wheels	15	9	0
Total, in working order ...	44	3	0

Tender: Water capacity ...	4,000 galls.
,, Coal capacity ...	5 tons.

The Simplon Tunnel.

At a recent meeting of the Institution of Civil Engineers, Mr. Francis Fox, M.Inst.C.E., gave some interesting information concerning the construction of the Simplon Tunnel.

After touching upon the history of the Simplon Pass over the Alps, and the roadway built by Napoleon in the four years preceding 1805, Mr. Fox described the present tunnel, which was adopted out of about thirty different proposals.

The chief feature of this route is its small altitude (2,313 ft.) above sea-level, which compares favourably with other Alpine tunnels. In the tunnel the gradients were decided primarily by assuming that the progress of excavation would be the same from both ends, and secondly by the least fall capable of giving efficient drainage; thus a minimum of 1 in 500 was adopted for the north side, and 1 in 143 for the south side, the two gradients being joined by a vertical curve in the centre.

The work provides for two parallel single line-of-way tunnels, 55·8 ft. apart, connected by oblique cross passages; the reasons for this arrangement were:—(1) Ventilation during construction; (2) greatly reduced pressure on the tunnel lining; (3) increased facilities of transport and drainage during construction; (4) increased facility in subsequent maintenance during traffic; (5) safety in working traffic.

One tunnel only has been completed to the full section, the second gallery being left at present as a heading.

The completed tunnel measures 16 ft. 5 ins. in width and 18 ft. ½ in. in

height above rail-level. It is lined throughout with masonry. Refuges and chambers are built into the cross passages for use by the maintenance-gangs.

In December, 1890, Messrs. Sulzer, of Winterthur, and Messrs. Brandt, Brandau & Co., of Hamburg, presented the plans, and in 1895 the Swiss and Italian Governments ratified a convention for the construction of the tunnel. The cost was estimated at £3,040,400, towards which the two Governments contributed; the period of construction was to be 5¾ years. The actual cost is about £3,200,000 and the period taken 6¾ years.

On the death of Mr. Brandt, Colonel Locher-Freuler, of Zürich, joined the firm of contractors. Dr. Max Rosenmund, of Zürich, carried out the triangulation, and was responsible for the setting-out of the tunnel.

In August, 1898, the excavation was commenced with the pick, pending the installation of hydraulic power; at Brigue the "Brandt" hydraulic drills began work on the 22nd November, 1898; but at Iselle, owing to the necessity of transporting all plant over twelve miles of steep roadway, drilling was not started till the 18th February of the following year. The two ends were worked on the same general plan, each independently: about 2,000 h.-p. was developed both from the Rhone and the Diveria, driving high-pressure hydraulic pumps.

A full description of the "Brandt" hydraulic rotary drill and its capabilities is alluded to in the paper, with methods of blasting. Ventilation was effected by fans; the air, forced into the mouth of one of the galleries, travelled by the parallel gallery, the latter being used as means of exit and entry for the trains of material, &c.

The whole works were kept remarkably fresh. To supply the men working in the faces, air was taken from near the last cross cut, cooled by means of a fine jet of water and driven through light iron pipes to any desired point. Later, on meeting the hot springs, the air was cooled at various points in the finished heading by means of jets of cold water spray. Though in the St. Gothard a temperature of 93° F. proved in many cases insupportable, yet in the Simplon, owing to the excellent ventilation, a temperature of 133° F. was not unbearable. Diagrams are given in the paper showing the relation of the temperature in the tunnel to the height of the mountain above it.

On leaving the tunnel the workmen entered a large warmed building fitted with dressing rooms, and with hot and cold douche baths. Here they changed into warm dry clothing, and their mining garments were dried or washed ready for the next day.

The work of excavation progressed rapidly at both ends, an advance of 18 ft. per day being frequently recorded. On the Swiss side the rock encountered was chiefly gneiss and micaceous schist. On the Italian side, after traversing about 2¾ miles of hard Antigorio gneiss, the thermometers in the rock showed a diminishing temperature, and suddenly a cold underground river of 12,000 galls. per minute burst in. Owing to the treacherous nature of the rock at this point, only heavy joists buried in quick-setting concrete were able to hold open a heading of sufficient area to give access by small hand wagons to the drills beyond. This short length entailed a delay of 6 months.

After traversing another 2¼ miles, hot springs with a maximum flow of 4,330 galls. per minute and a temperature of 45·4° C. were encountered, but by taking the water of the cold spring and throwing it into the crevices of the hot, the heading was made bearable.

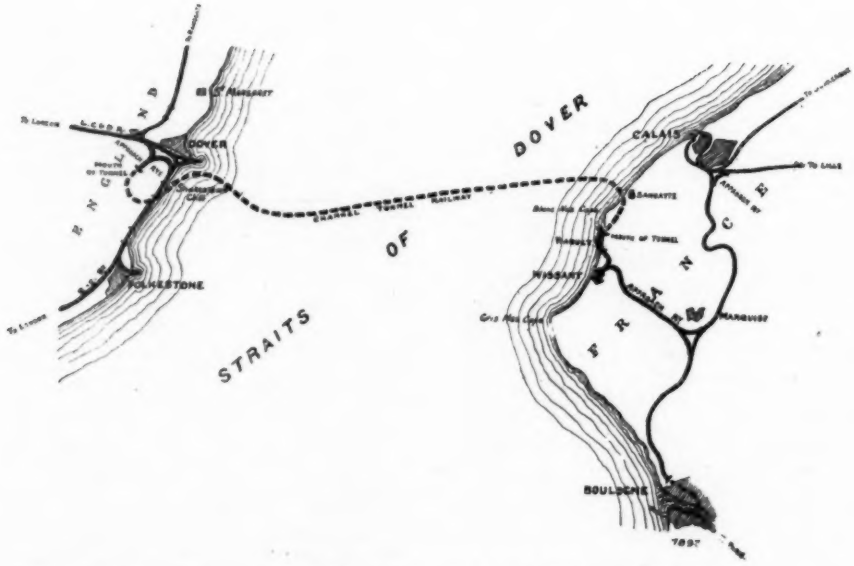
During these delays to the south end, the north had been advancing with increasing rapidity, and had reached the central summit of the tunnel: to avoid delay, however, the heading, hitherto on the level of the floor of the tunnel, was made to rise on a gradient of 1 per 1,000.

When the advance heading reached the soffit of the future tunnel, working downhill was attempted, but finally work on the Swiss side was abandoned,

the drills were withdrawn, and the heavy iron doors which had been erected were closed (March 20th, 1904). Completion was thus left to the south advance, whose drills could just be heard through the intervening 1,094 yards of rock.

On the 24th February, 1905, at 6 a.m., the final charges on the Italian side were exploded in the roof of the gallery, blowing a hole about 8 ft. by 2 ft. into the floor of the Swiss heading above.

The first train passed through on the 25th January, 1906, and on the 19th May the King of Italy travelled in a special train to meet the Swiss President at Brigue, who returned with him to Domo d'Ossola; the final opening to the public taking place with great festivities on the 30th May, 1906.



MAP SHOWING APPROACHES TO AND LINE OF DIRECTION OF THE PROPOSED CHANNEL TUNNEL.

(For description see p. 77.)

Electrical Engineering Notes.

By ANDREW STEWART, A.M.I.E.E.

Automatic Electric Signalling on Railways.

The paper read on this subject at a recent meeting of the Institution of Electrical Engineers by Mr. H. G. Brown was an unusually lucid exposition of a subject which has been almost entirely neglected by British engineers. Whether they prefer to wait until a practicable system of signalling directly on to the train is evolved, or find the present system satisfactory enough for most purposes, we are not prepared to say, but the many interesting features of the system of automatic signalling, now largely used on American railways, and employed on several of London's underground railways, as well as at Glasgow and Newcastle - on - Tyne, justify more than a passing reference, and certainly did not warrant cutting down the discussion to the narrow limits imposed at that meeting. Stripped from its complexities, the system consists of a relay which is connected from one running rail to another, and a battery at one or other end of the section. Under normal conditions, *i.e.* when no train is passing over the track, sufficient current passes through the relay to hold its armature clear of the contacts which close the circuit operating the signal.

As soon as a train comes on to the section, the relay is shunted by the wheels and axles of the train, so that the current that passed through the relay is no longer sufficient to hold the armature, which, when it drops, closes a circuit supplying current to a small motor which raises the signal to danger, or, in the case of an electro-pneumatic system, opens a valve, which allows compressed air to pass into a cylinder, and so raises the signal to danger. As soon as the train has passed out of the section, the current in the relay becomes strong enough to lift the armature again, as it is no longer diverted by the wheels and axles of the rolling stock, so that the signals show line clear.

A description of the electro-pneumatic system in use on the Great Northern, Piccadilly, and Brompton Railway was given in our January issue.*

The disturbing factors with such a system of signalling are that, in addition to the temporary short circuiting of the relay by the train, it is permanently short circuited by the track, the current in which varies with the dampness of the ballast, and may vary within wide limits, depending upon whether or not the ballast will absorb much or little water. It appears that in practice this ballast resistance varies from 4 to 18 ohms per 1,000 ft., and may fall to as low as 1½ ohms in wet weather, while in damp tunnels it may even be ¼ ohm permanently, so that a widely differing range of adjustment and winding of the relay is called for; even with this wide variation, sections as long as a mile can be operated satisfactorily. The principal difficulty, apart from the variations in the ballast resistance, is that excessive sanding, by increasing the resistance between the wheels and the rails, may make the operation of the apparatus uncertain. It appears that ordinary sanding exerts no appreciable influence.

In the case of "Mansel" wheels used on several railways, the hubs must be bonded to the tyres as of course the wood effectively prevents any current passing. The London and North-Western Railway rolling stock, which uses the District Railway, have the wheels bonded, and are quite satisfactory. On steam railways the relay

* Page 62.

works with about ·015 watt, as there are no disturbing currents; but in the case of electric railways it is desirable to use a fairly high pressure between the rails, for there the possibility of one rail carrying more return current than another would introduce differences of potential between one rail and another, which is not allowed for in the adjustment of the relay.

Polarised relays, *i.e.* relays which are sensitive to a current flowing in one direction only, may be employed in such cases; they are also used to operate distant signals by means of the reversal of the track circuit, so that the long live wires between the distant, and the home signal which controls it, are unnecessary.

Electric Driving in Railway Shops.

The reorganisation of the works of the Erie Railway Company, at Hornell, New York, provides several examples of electric driving which are specially interesting, as both group and individual drives are employed. Such tools as are likely to be used for special repair work and are therefore liable to be employed when the main machinery is at rest, have been equipped with electric motors irrespective of other considerations, though most of the tools so fitted are of a type which renders this economically practicable.

The main generating station differs from standard British construction, inasmuch as horizontal moderate speed engines are employed. This type of engine would be considered unduly wasteful of ground space and capital in this country, but as the high standard of perfection, which is a characteristic of the British high-speed engine, is not shared by this type of engine as produced by American engineers, the extensive use of moderate-speed engines when the units are not large enough to make the steam turbine an economical unit, is not to be wondered at.

There are three "Ball and Wood" engines, two of 500 h.-p. each and one of 400 h.-p., the former running at 150 and the latter 200 revolutions per minute, direct connected to direct current generators of 300 and 200 kilowatts respectively. As it may be found expedient to extend the station with polyphase alternating current plant to meet a probable demand from places some distance from the main shops, a motor generator, consisting of a direct current motor of 115 h.-p., coupled to a 75 kilowatt two-phase alternating current generator, giving a 60 cycle current at 1,040 volts is installed. This plant will serve as a link between the two systems, but meantime it is used to convert the direct current to alternating current, which is used to light the yards and depôt.

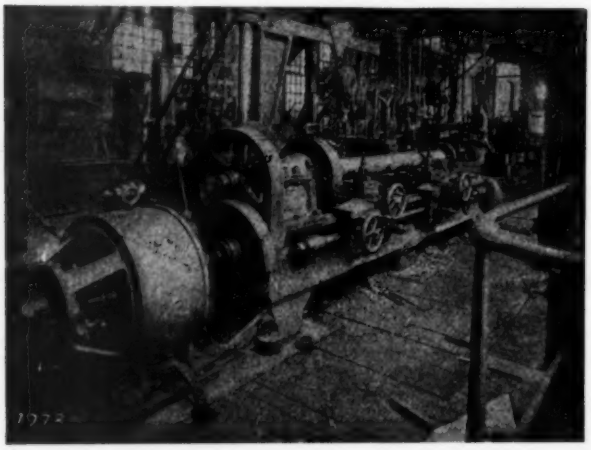


FIG. 1.—LATHE DRIVEN BY 20 H.-P. MOTOR

As pneumatic tools are largely used in the shops, there are two "Ingersoll - Sargent" compound air compressors installed in the generating station. The switchboard is of a standard pattern, and presents no features of unusual interest.

The system of distribution is three-wire with 250 volts between the outer wires, giving 125 volts from either wire to the neutral. In addition to incandescent and arc lamps operated on the 125 volt circuits, there are a number of "Cooper-Hewitt" mercury vapour lamps.

Driving in the machine shop is largely to groups of machines, the motor being in the case of three groups, a 50 h.-p. motor, and in the case of two a 30 h.-p. motor. The machines comprising one group, and characteristic of the other groups, are as follows: 50 h.-p. "Westinghouse" constant speed motor driving two wheel presses 300 and 100 tons capacity, car wheel borer, double and single car axle lathes, four spindle drill, horizontal boring machine, 15, 16, 18 and 24 in. engine lathes, 80 in. driving wheel lathe, 10 in. slotter, 37, 42 and 53 in. vertical boring mills, No. 4 milling machine, 28 and 36 in. vertical drills, 24 in. shaper, 32 × 32 × 8 ft. planer, 90 in. quartering machine, 40 in. vertical boring mill, 1¼ in. by 24 in. turret lathe, duplex emery grinder, seven spindle nut tapping machine, and flange punch.

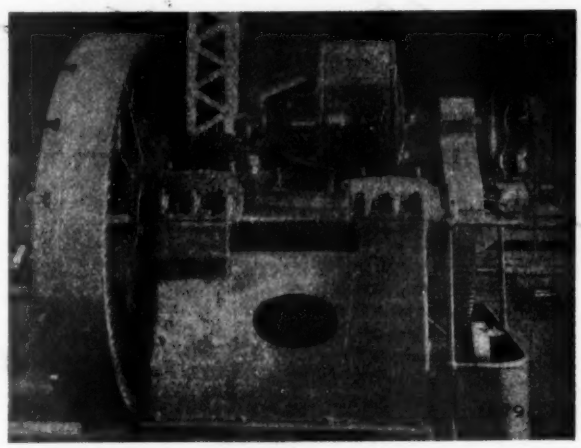


FIG. 2.—WHEEL LATHE DRIVEN BY 40 H.-P. MOTOR.

Of the individual drives we give two examples: Fig. 1 showing a 20 h.-p. motor direct connected to a lathe, and Fig. 2 a 40 h.-p. motor geared to a driving wheel lathe. The method of attaching the motor will prove of interest to those of our readers who are likely to deal with similar conversions. In a previous issue* we gave full particulars of a more comprehensive conversion to electric driving.

An Electrically-Operated Main Line Railway.

There are so few examples of a complete conversion to electric working on a line operating both express and local traffic, that the following description of what has been done on the Camden and Atlantic City Railway should prove of interest. The line is a section of the Pennsylvania Railroad, and the distance from Camden to Atlantic City *via* Newfie d is 65 miles. There is also a small branch line electrified, the whole electrified portion amounting to 150 miles of single track.

The generating station, shown in section, Fig. 3, contains three 2,000 k.w. "Curtis" turbo-alternators, giving a total generating station capacity of 6,000 k.w. or 8,100 h.-p. There is room for another 2,000 k.w. generator, and considerable extension can be effected by extending the engine room at one end, where there is a temporary wall. The turbines are fitted with barometric condensers seen in Fig. 3; these will condense 60,000 lbs. of steam per hour and maintain a vacuum of 28 in. The ratio of condensing water to steam is 75 to 1. The centrifugal circulating pumps are driven by steam engines, so also are the exciting sets, which consist of horizontal "Curtis" turbines and direct current dynamos. The reason for driving these auxiliaries by steam instead of electric motors is that the exhaust steam from

* THE ENGINEERING REVIEW, December, 1906, pp 433–436.

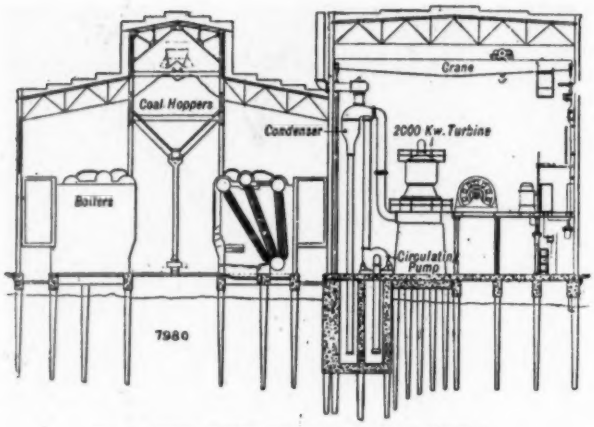


FIG 3.—CROSS SECTION OF MAIN GENERATING STATION.

them is profitably used for heating the feed-water. There are two feed-water heaters, each capable of heating 135,000 lbs. of water per hour from 70° F. to 212° F.

As the main generating units are vertical, the step bearings for these require a water supply, which is provided by "Worthington" pumps, and a hydraulic accumulator having a capacity of 100 gallons at 800 lbs. per sq. in. pressure.

Steam is supplied by twelve "Stirling" boilers, each rated at 358 h.-p. with a working pressure of 175 lbs. per sq. in. Each boiler is provided with a superheater giving 125° F. superheat to the steam. The coal and ash handling plant is entirely automatic. The generators give three phase 25-cycle current at a pressure of 6,600 volts; this is transformed up to 33,000 volts for transmission by an overhead line, parallel to the railway track, to the substations, of which there are eight. This high pressure transmission line has a total length of 71 miles, and is in duplicate throughout. One of the poles is shown in Fig. 4; they are of chestnut generally 45 ft. long, extra long poles being used where necessary. Poles are usually spaced 125 ft. apart, but at special places, curves, &c., this distance is reduced to 100 ft. As will be apparent from Fig. 4, the six transmission wires form two inverted equilateral triangles, the insulators being 42 in. apart.

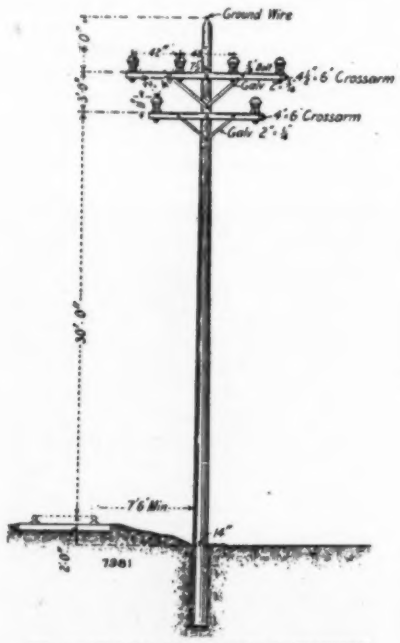


FIG. 4.—POLE FOR HIGH TENSION TRANSMISSION LINE.

Each insulator was tested to 85,000 volts for ten minutes. The ground wire for protecting the transmission line from lightning consists of a seven strand galvanised steel cable strung along the top of the poles 4 ft. above the nearest active wire, and connected to the ground at every fifth pole. Lightning arresters are fitted to the transmission line at the generating station and substations as an additional precaution.

The transmission line was erected at the rate of from one-half to two miles per day, which included stringing the line wires.

The substations, one of which is shown in section, Fig. 5, are fitted with air-cooled transformers, and rotary converters. The transformers reduce the pressure from 33,000 volts to 430 volts three phase, it is then converted to 650 volts direct current by the converters.

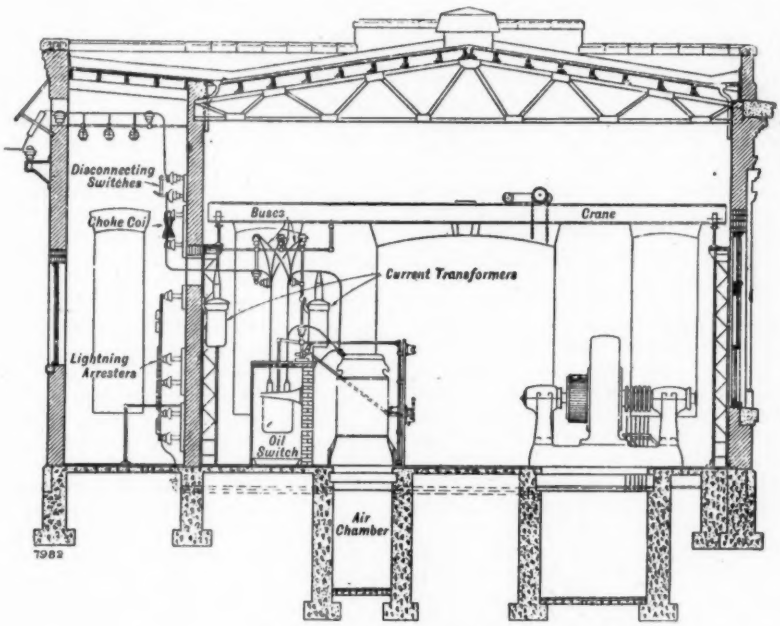


FIG. 5.—SECTION OF SUBSTATION.

The erection and equipment of the substations were carried out very quickly; erection, including foundation, required sixty working days, and the installation of the machinery thirty days.

The third rail is standard Pennsylvania Railway Co. rail, weighing 100 lbs. per yard, in lengths of 33 ft. It is carried on insulators of reconstructed granite, and is fixed thereto by a metal clip. The insulators are 10 ins. long by $5\frac{1}{2}$ ins. broad at the base, with a depth of $3\frac{1}{2}$ ins. between the bottom of the rail and the tie, spaced 8 ft. apart. This rail and the running rails were bonded at the rate of 660 per day.

A branch section of the line 10 miles long is worked on the overhead trolley system, so also is part of the line in Camden, the trolley wire being suspended 22 ft. above the track, and carried by span wires from poles 100 ft. apart; when practicable the high tension transmission line poles are used to support the span wire on the side of the track.

A distinctive feature of the rolling stock is that every car is a motor car, so that while trains consist of two to three cars, the rolling stock can be used as independent units. Each car is mounted on two bogies, only one of which carries motors. The seating capacity of each car is fifty-eight passengers, and they are $55\frac{1}{2}$ ft. long over the buffers, the

bogie centres being 33 ft. The car weighs 40 tons without passengers. Combination luggage and mail cars of the same general dimensions are also used. They are divided into a luggage compartment 29¾ ft. long, and a mail compartment 20 ft. long. Each car has two trolleys as well as contact shoes for the third rail, and passenger cars are heated by "Gold" heaters under the seats, similar to those used on the District Railway (London).

Three-car express trains attain a speed of 60 miles per hour on straight level sections of the line; at present there are three-car express trains running between Camden and Atlantic City, a distance of 65 miles in 90 minutes; this average speed of 43 miles per hour will be improved later. There is also a local service of two, three, or four cars every 15 minutes, as circumstances demand, between Camden and Glassboro, and single cars run between Camden and Woodbury every ten minutes.

Regenerative Control on Electric Tramways and Railways.

The large amount of energy spent in wearing down brake blocks, wheels, and rails, during the period of retardation on a tramway or a railway, or the continuous braking effort on a vehicle, or train of vehicles, descending an incline, has always proved a matter which excites the sympathetic interest of every engineer who has ever seen the process, and some means of recovering some, if not all, this wasted energy has frequently been thought about, but as frequently discarded as beyond the scope of practice.

With compressed air locomotives and cars some means of storing a little energy by utilising the forces already referred to, has been put into practice, but the application of compressed air to traction was always so limited that no general benefit has been, or is likely to be, derived from any such arrangement, as it involves not so much the regeneration of lost energy as the regeneration of an obsolete system of traction. The action of a cable car when descending an incline, in exerting a pull on the rope, and so helping other cars on a rising incline, is another example of regeneration, which, however, as the critical speed is also the normal working speed, cannot be used, say, when the car is being brought to rest.

With electric traction on the other hand, there is a fair range of speed at which the motor, or for the time being generator E.M.F., may be sufficiently high to return an appreciable amount of energy to the line, and as this may be used every time the car is brought to rest, as well as when descending an incline, the possibilities of such a system are considerable.

The subject has recently been dealt with by Messrs. Alfred Raworth and E. H. Johnson, and both have not only made out a good case for regeneration, but, especially the former, backed their arguments with evidence of substantial financial advantages.

One must bear in mind that a good deal of energy used in electric traction might be saved if rapid acceleration were not demanded, but, this is essential if high average speed is to be maintained; moreover, the kinetic energy of a moving car or train is not so great as the energy required to accelerate it rapidly, but it is nevertheless a sufficiently large percentage of it to make it worth some capital expenditure in order to recover it. The obvious advantages of regeneration are so great that only the self-regulating properties of the series motor, its high initial torque and high speed under small loads, prevented its being abandoned long ago in favour of the shunt motor, by which means alone regeneration was deemed practicable.

Mr. John S. Raworth and, later, Mr. Alfred Raworth have evolved a system which is a development of the simple shunt motor with which they started out. The motors are still shunt wound machines, but when two motors are running in parallel they have some series excitation. The "Johnson-Lindell" system is, on the other hand, a hybrid arrangement, inasmuch as when the motors are acting in their normal capacity they are

series wound, but when their functions are reversed, and they become generators, they are connected as shunt wound machines.

To enable this arrangement to be carried out, the motor armatures are double wound, with a commutator at each end of the armature, and the shunt field windings are connected in parallel with each other. When the machine is acting as a motor these parallel connected shunt coils are connected in series with the series field coils, so that, notwithstanding the dual functions of machine, the whole of the copper on it is active, whether it operates as a generator or a motor.

When the motor is returning current to the line, the series windings oppose the shunt windings. This keeps down the field flux, and, therefore, the generator E.M.F., and so prevents any excessive current being returned to the line. This would not, of course, be very objectionable, but, apart from the excessive braking effect, would be liable to seriously overheat the motor.

This question of heating is an important one, as an ordinary traction motor is working all day on a widely varying load, so that the average load is much below the maximum; not only so, but the machine has considerable periods when it does no work, such as when coasting, during the period of retardation, and when descending an incline on the brakes. With regenerative control, however, the motor is working with its functions reversed during the two latter operations, so that it has no time to cool, and, indeed, owing to iron and copper losses, a considerable increase in temperature may be expected.

This is what does take place, but if the figures put before the meetings of the Institution of Electrical Engineers at Leeds and Manchester indicate anything, they show that this rise of temperature is not sufficient to endanger the insulation.

The financial advantages of regenerative control appear to be considerable. Mr. Alfred Raworth showed that with the "Raworth" system, savings varying from 24 to 28 per cent. were obtained. For instance, at Bristol, two cars, one with regenerative control, and one with ordinary series parallel control, each travelled 44·18 miles over the same track on a wet day; the car with regenerative control used ·871 units, and the car with series parallel control, 1·15 units per car mile, a saving of 24 per cent. in favour of the car with regenerative control. On the Crystal Palace route of the South Metropolitan Tramways Co., a saving of 28¼ per cent. was recorded.

This saving means, *inter alia*, a saving in distribution losses and a reduction in both the maximum and the mean load, so that, in addition to a substantial saving in fuel, there is a reduction in the capital required for the generating and distributing system.

In addition to all these savings, there is the obvious reduction in the cost for repairs and renewals of wheels, brake shoes and brakes. This Mr. Raworth estimated at £15 per car per annum.]

Metallurgical Progress.

By PERCY LONGMUIR.

GENERAL METALLURGY.

The Zinc Resources of British Columbia.*—From the report of the Canadian Commission appointed to investigate the zinc resources of British Columbia and the conditions affecting their exploitation it appears that the production of zinc ore in the Slocan district has already attained considerable proportions. In 1899 the shipments amounted to 1,600 tons, a total increased to 8,561 tons in 1905. The report criticises methods of mining practised in the district, and it is pointed out that money has been wasted through unwise development. The possibility of enriching the ore by magnetic concentration was demonstrated by tests conducted by the Commission. A wide variety of ores, representing all grades produced in the province were tested and concentrates assaying over 40 per cent. zinc obtained in all cases, whilst in a few cases concentrates as high as 57 per cent. were obtained. These results compare very favourably with American, European or Australian practice. The markets open to zinc ore are indicated, and a disadvantage in the case of America shown in the imposition of a 20 per cent. tariff. Concerning home smelting the plant under construction at Frank, Alberta, was not complete at the time of the preparation of the report. However, from an analysis of all items in the cost of production and delivery, it is concluded that zinc smelting in Canada is commercially feasible, especially since part of the product can be disposed of in the home market. The question of electro-thermic smelting has been considered, but in view of the infancy of this art, little definite advice is offered. From present developments and theoretical calculations the conclusions drawn are:—

(1) Electric smelting will never displace ordinary smelting if it be necessary to generate the power from coal.

(2) Electric smelting may in the future be economically conducted at places where cheap hydro-electric power is available.

(3) Aside from the question of power, up to the present time certain peculiar and serious difficulties in electric smelting have not been satisfactorily overcome. It is possible that at some future date the water power on the east coast of British Columbia and also in Eastern Canada may be utilised for the electric smelting of zinc and other ores, but any such development is a matter of the future and is not to be reckoned upon at the present time.

* *The Engineering and Mining Journal.*

A Process for Oxidising Metallic Sulphides in Ores.—Messrs. N. Lebedeff and B. Pomeranzoff give in *The Engineering and Mining Journal* a process of oxidising metallic sulphides in order to fit the ore containing them for final treatment by wet or dry methods. The crushed ore is mixed with clay and the mass submitted to the gradual action of heated air at a temperature of from 300° to 400° C. As the oxidation of the sulphur proceeds very energetically when the clay used contains much iron, it must be admitted that in this case oxidation is not due so much to the direct penetration of air into the charge as it is to oxide of iron in the clay. The amount of clay varies according to the quality and to the quantity of sulphides in the ore, an average being formed in one volume of clay to one volume of ore. The process is used in connection with the smelting of copper ores at Nijni Tagilsk, Russia.

Alloys of Zinc and Iron.—Mr. S. Wologdine records, in *Revue de Metallurgie*, an experimental investigation of these alloys. At the outset the author states that, owing to their fragility, alloys of iron and zinc find no direct industrial application, nevertheless they play a certain *rôle* in the production of special brasses as a means of introducing iron in determined quantities. Thus Dick in preparing Delta metal advises a saturated solution of iron in zinc, the content of iron being 8 per cent. In the case of galvanising it is shown that an alloy of iron and zinc is gradually formed which falls to the bottom of the bath, provided agitation and quick heating are avoided. According to the researches of Berthier the upper part of the bath contains 0·2 per cent. iron, whilst the alloy in the lower part is homogeneous and contains about 4·3 per cent. iron. If the temperature is raised too high an alloy is formed which contains 9·5 per cent. iron. Calvert and Jonson on analysing the deposit formed in a galvanising bath found 6·06 per cent. iron which nearly corresponds to the formula $FeZn_{13}$. As it is impossible to prepare alloys of iron and zinc by direct fusion, owing to the volatilisation of zinc, the author has followed the indirect process recommended by Dick. To effect this small pieces of galvanised iron wire were placed in the bottom of a crucible which is then filled with molten zinc, the surface

covered with charcoal and the whole placed in a gas furnace for one hour at a temperature of from 700° to 800° C. The resulting alloy differed from zinc by its hardness and by its property of falling into a powder composed of grey crystals, the analysis of the latter showing an average content of iron at 8 per cent. This alloy has served as a base for the production of others in which the content of iron has been varied. From a micrographic examination of these alloys it is shown that iron in contents below 8 per cent. is very soluble in molten zinc. The alloys of zinc and iron give no solid solutions with the range examined by the author. The definite compound of iron and zinc gives the formula $Fe\ Zn_{10}$, which corresponds to 7·88 per cent. iron and is fusible at a temperature of 750° C. From a series of solidification point determinations it is shown that the fusion point increases with the iron, thus the pure zinc point of 420° C. is by the addition of 8·57 per cent. iron raised to 750° C.

Thermal Treatment of Metallurgical Products.*—M. Guillet, in a lengthy memoir, discusses many aspects of theoretical metallurgy, but with one exception no specially new features are brought forward. The exception is found in the following statement: "The carbonists—if any still exist, which is very doubtful, their chief, M. Arnold, Professor of Sheffield, having abdicated—very cleverly pretend that the carbon has the preponderating influence without denying, however, that the allotropic forms of the iron act or operate."

M. Guillet is an exceedingly clever man, and, as one of his distinguished *confrères* remarked to the present writer, is a manufacturer of researches which make up in quantity their omissions in quality. To these qualifications one is regretfully compelled to add that of inconsistency, for the quotation given is by no means true. Professor Arnold's adherence to the carbon standard, his classical work on the influence of carbon, are familiar to the whole of the metallurgical world, and, we might add, painfully familiar to many who have attempted to dispute his conclusions. However, this aspect is one of which we have no doubt that Professor Arnold will personally attend to. Another aspect is found in the fact that every producer of steel by pretending that the carbon which he so carefully regulates has a controlling influence is deceiving not only himself but his customers also. In other words, the crucible steel makers of, say Sheffield, have from Huntsman's day to the present been living in a state of pretence, for even to-day they actually vary the content of carbon to suit the purpose for which the steel is intended. Personal contact with these steel makers is such as to lead to the conclusion that as a body they are not men who wilfully deceive themselves or others. A remark by one of them is worth quoting, and runs as follows:—"If M. Guillet will make a milling cutter or razor equal to the average commercial article from pure and carbon-free iron, then I will accept his statement that I and my ancestors have been living in a state of pretence; until then I prefer to rely on the teaching of my daily experience."

Finally M. Guillet should prove his assertion of pretence, and if we may venture to advise him would say that steel makers as commercial men are only too anxious for facts, and will heartily welcome any he cares to present. Mere statement is of necessity disregarded by men whose time is fully given to the production of steel and to a study of its intricacies.

Zinc and Arsenic.—Messrs. Friedrich and Leroux record in *Metallurgie* experiments on the preparation of these alloys. A solidification curve of the alloys containing from 0 to 13·9 per cent. arsenic shows a line about 419° C. which corresponds to the separate not of arsenic but of mixed crystals of arsenic and zinc, which may possibly be an alloy of the two bodies. Chemical and microscopical examination show strong tendencies to liquation in the alloys.

Silver and Arsenic.—Messrs. Friedrich and Leroux give in *Metallurgie* a study of the solidification of these alloys for contents of arsenic varying from 0 to 19 per cent. The following temperatures show the influence of an ascending content of arsenic:

Arsenic per cent....	0	2	4·8	9·6	13·4	19
Temperature ...	962°	934°	877°	773°	667°	590°

Within the limits examined, the curve of fusibility has shown no maximum indicating that there is no separation of a compound of silver and arsenic.

Microscopical examination of the alloys shows white crystals of silver embedded in a greyish yellow ground. As the arsenic increases up to 19 per cent. the proportion of entectic regularly increases without presenting any new constituent. Under the conditions of these experiments the alloys have shown no tendency to segregation.

Volatility of Blende.—Messrs. F. Doeltz and G. Graumann give in *Metallurgie* the results of experiments on the volatility of Spanish blende. The blende was dried to a constant weight at 600° C., and then heated in a platinum resistance furnace to 1,000° C., with the following results:

Temperature.	Loss.	Time of heating.
1000° C.	0·36 per cent.	½ hour
1000° C.	4·60 ,,	1 ,,
1000° C.	51·0 ,,	3 ,,
1000° C.	26·0 ,,	3 ,,

The last result is obtained from a sample weighing about a third that of the sample immediately preceding it.

FOUNDRY PRACTICE.

Converter Steel Castings Practice.—In the third article of this series, Mr. A. Simonson describes the operation of "blowing."

* "Mémoires and compte rendu des Travaux de la Société des Ingénieurs Civils de France."

At the outset the cupola metal must be hot and a higher fuel ratio than 1:7 cannot be expected. In some plants the cupola is of sufficient size to give two tons per tap, in others the cupola is arranged to hold one ton, thus making two taps per blow. This has an advantage in that the iron remains a shorter time in contact with the coke and is therefore less liable to absorb sulphur. Whilst the cupola is being charged the converter is heated for the first blow, the usual plan being to make a coke fire and blow it with about 1 lb. pressure from the blower. In order to heat the bottom of the converter, which is not reached by the blast, a plate is fastened over the mouth to retain the coke and the converter turned upside down every alternate fifteen minutes. Oil or natural gas may replace coke for this preliminary heating. The converter should be heated and cleaned from coke by the time the first charge is ready from the cupola. The charge is transferred to the converter, which is then turned down until the iron just comes to the lip, thereby permitting of an effective skimming and the removal of all slag. The vessel is then turned up again and as it rises the operator looks through the tuyeres and arrests the rotation when the convex edge of the molten metal just appears over the edge of the tuyere. It is important that the metal should be up to but not in the tuyeres. When the right level of metal has been obtained the position of the converter is noted by means of an indicator, which simply consists of a quadrant attached to the rotating gland and a fixed pointer. The best position for blowing is with the indicator from five to nine degrees back from the vertical, that is, with the tuyeres slightly inclined towards the surface of the metal. If the angle appears too great or too small, a hand ladle may be taken out or added as the case may be, but once the correct amount of metal has been determined there should be no difficulty in adding suitable quantities for subsequent blows. After this adjustment, the tuyere box covers are fastened in position and blast admitted, the motor being speeded up to give 3 lbs. on the mercury gauge when the bye-pass valve is entirely closed. At the beginning, sparks and smoke accompanied by very little flame issue from the mouth of the converter. The sparks should be copious, large, and scintillating, and of a light yellow colour; whilst the smoke should be noticeable, not too voluminous and not too dark brown in colour. An experienced operator, judging by these indications, will tell during the first minute whether the silicon of the charge is right and whether the blow will be normal or otherwise. In from three to five minutes the sparks become non-scintillating and at the same time a flame should appear at the mouth of the converter. This indicates the beginning of carbon oxidation, and the upper tuyeres should be slightly opened in order to complete the combustion of the carbon and so reap the full benefit from the heat generated. At the same time the position of the converter should be advanced two or three degrees to compensate for the shrinkage in volume. During the next four or five minutes the flame continues to increase in volume and brightness until the "boil" is reached. The flame is carefully watched, and if there is any tendency to eject metal, the blast pressure may be reduced, in any case, a certain amount of slag is always ejected, but this is immaterial unless it interferes with the free observation of the flame. After maintaining its top position for one or two minutes the flame dies down somewhat and remains quiet for some minutes. The upper tuyeres are then fully opened and the flame rises again, becoming bright and clear, and finally dies down with the evolution of copious brown smoke. The blow should be turned down a few seconds before the brown smoke appears, as this indicates burning iron. The end, when correctly caught, results in the vessel containing a fluid bath of practically

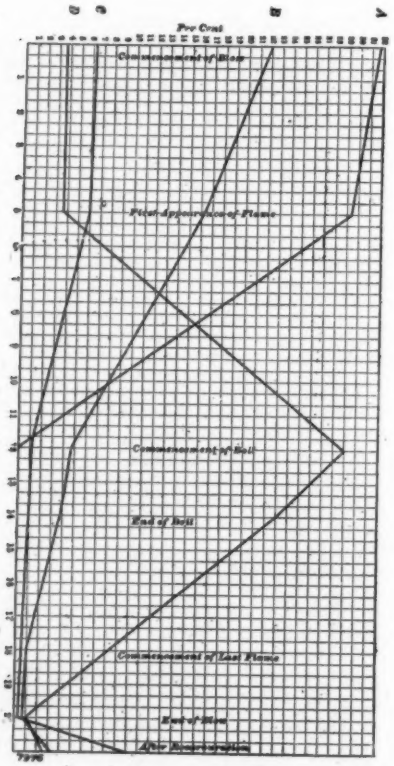


FIG. 1.—CURVES OF ELIMINATION OF ELEMENTS IN A TYPICAL BLOW.

NOTE.—Line *A* is for graphitic carbon; line *B* for silicon; line *C* for manganese, and line *D* for combined carbon.

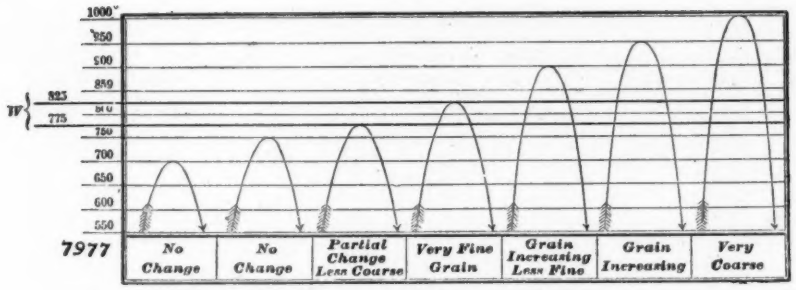


FIG. 2.—HEAT TREATMENT AND ANNEALING OF STEEL CASTINGS.

pure iron, which may be recarburised to the desired point by means of ferro-manganese, ferro silicon, &c. These additions may be added in a molten state, or they may be thrown in cold at the mouth of the converter, immediately after turning down and before the slag gets too hard. The writer's plan, which we take it will require some little dexterity, is to first dip the lumps in water, so that the explosion of the vapour as they strike the hot slag will split them and allow the alloy to evenly enter the bath. The chemical changes occurring during the blow are shown in the appended elimination curves (Fig. 1).

Heat Treatment and Annealing of Steel Castings.*—Mr. W. M. Carr, in the eleventh instalment of a series on "Open Hearth Steel Castings," discusses some aspects of the annealing of steel castings. Practically the writer's views are summed up in the above diagram, representing the structural changes induced in steel of 0·25 per cent. carbon by heating to different temperatures. The following embodies some results obtained by the writer, illustrating the influence of treatment.

* *The Iron Trade Review.*

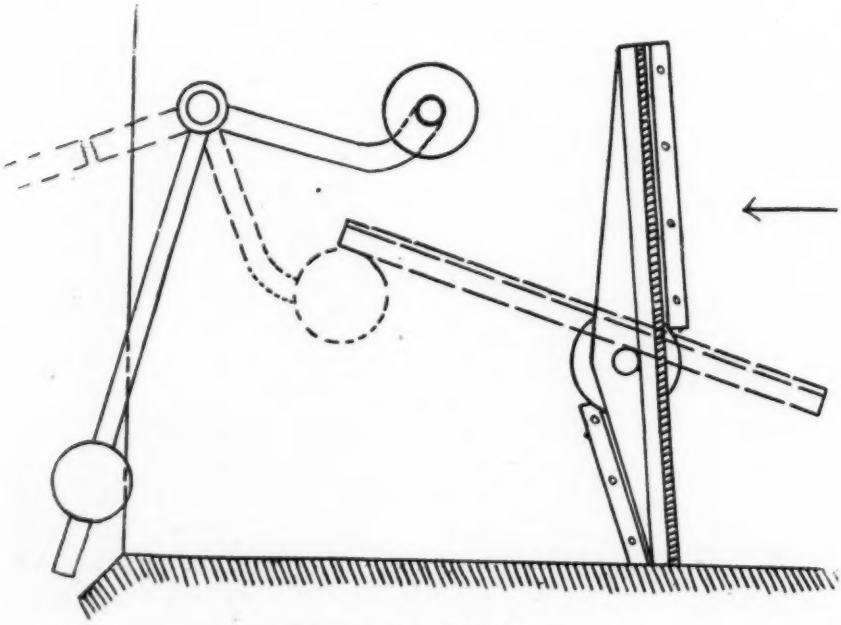
Tensile strength, pounds sq. in.	Elongation, per cent. in.	Contraction, per cent. in.	Treatment.
		SERIES I.	
80385	13·26	16·2	Metal as cast.
78767	27·20	40·4	Heated to "W."
79422	14·80	15·3	Greatly above "W."
		SERIES II.	
77779	26·5	28·5	Metal as cast.
74504	25·0	48·8	Heated to 830° quenched, reheated to 750° and air cooled.
78792	25·0	34·3	Heated to 815° one hour and air cooled.
74058	25·7	31·	Heated 24 hours at 850°. Cooled in furnace. Four hours in heating. Eleven hours cooling.
73376	24·2	26·7	Heated 36 hours between 850 to 900°. Heating up 3 hours 15 min. Cooling down 9:45.
90400	2·5	3	Heated to 1200° and quenched.

Automatic Gate for Waste Weirs or Dams of Storage Reservoirs.

NUMEROUS appliances are in use having for their object to secure the water that flows over a dam or waste weir when a flood begins to subside. The volume of this water is represented by the depth from the sill of the weir to the crest of water flowing over it during a flood, and although the dam is of sufficient strength to resist the full pressure of the flood, its storage capacity is limited to the volume that remains after the flood has drained away to the level of the sill, which is generally several feet lower. Barrages, consisting of banks of earth, planks and needles, present difficulties when it becomes a question of removal in case of sudden flood, the desideratum being a gate that will open automatically in such circumstances, allowing free passage to the water, and which will close automatically on its subsistence, thus retaining the water as near to the flood level as possible the pressure of which the dam was constructed to withstand.

An apparatus which has been successfully tested by the Bombay Government to effect this is known as the "Mirza" self-acting gate, the construction and action of which will be rendered clear by the aid of the accompanying drawing.

It consists of a gate hung on gudgeons



AUTOMATIC GATE FOR WASTE WEIRS.

THE GATE HALF OPEN.

THE GATE FULLY SHUT.

which turn in sockets carried in the masonry of the side piers. The gudgeons are fixed nearly at the centre of pressure, or about one-third the height of the gate from its base. The base closes against an iron sill and the edges below the gudgeons close against a joint strip attached to the side frames, a watertight joint being secured by means of an elastic steel tongue which presses against the edges of the gate. When water accumulates on the up-stream side, indicated by the arrow, the gate turns towards the position indicated by the dotted lines, and as the flood continues, opens until it touches the roller, which is carried on a bell-crank lever. The latter carries a balance weight which offers resistance to the increasing pressure of the water, which, during a heavy flood, brings the gate down to the stops shown. As the flood subsides the balance weight assists the gate to regain its normal position. A rise of $3\frac{3}{4}$ ins. of water over the top of the gate causes the latter to open and rest against the bell-crank lever until the water level rises to a further height of $3\frac{3}{4}$ ins., when the gate opens to its fullest extent.

The gate closes completely when the water level falls to 5 ins. below the top.

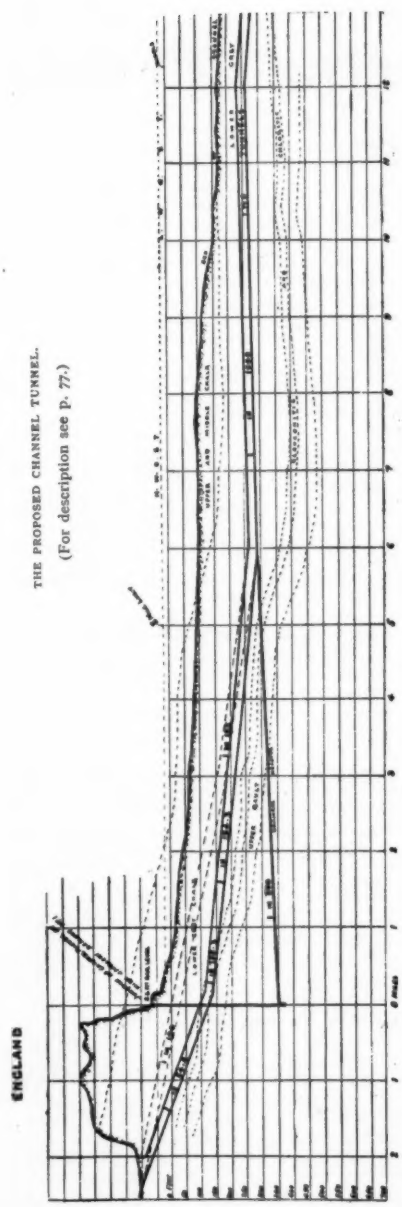
This action of the gate in retaining water which would otherwise be lost, it is stated, gives an increased storage capacity to a reservoir which is equal on an average to 40 per cent., and this is done without exposing the adjoining land to submergence or endangering the safety of the dam.

With regard to the tests above mentioned that were carried out on this gate, the Chief Engineer for Irrigation, Bombay Government, states that* "the advantage of Mr. Mirza's gate lies in the simplicity and the great saving it will effect by dispensing with the superstructure, arching, and the masonry chamber for the counter weights required with other gates." The gate was fairly watertight, although there were some small leakages at the sockets in which the axles move, which were, however, easily stopped by caulking. The metal springs used for the side frames above the axle level were 6 in. by $\frac{1}{8}$ in. bars of wrought iron hammered into the curved shape, and they answered their purpose very well.

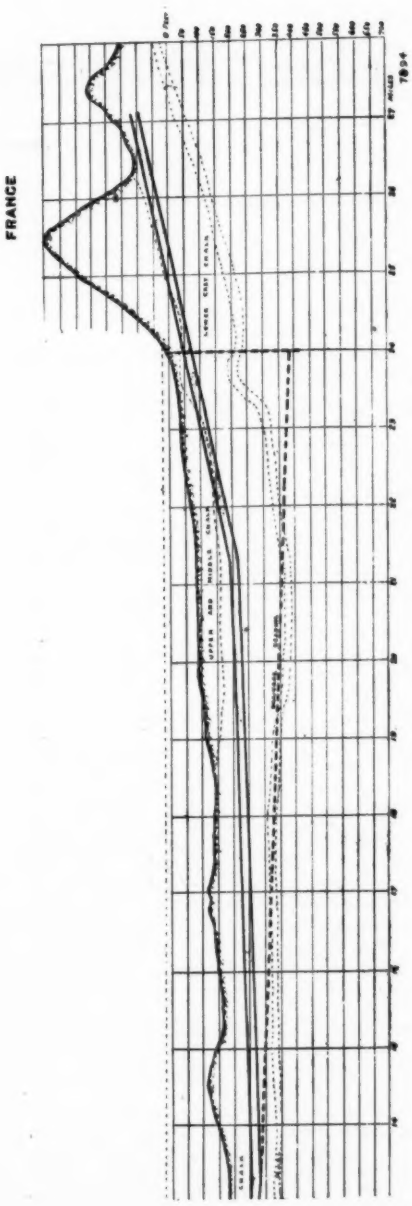
The report states that "the gate ought to work satisfactorily on reservoir weirs, where as a rule there is little or no floating matter brought down by floods, and where establishment is maintained for picking up any such matter that may come down. It is not a good form for river weirs because of the obstruction in the waterway. Any large floating object would probably damage the gate it struck. For canal escape and level crossings the gate seems to possess special advantages, and the counterweight could be made much lighter so as to permit of the maximum flood passing without any extra heading up. The gates need not close again until three-quarters or even half of the depth of water is lost."

In connection with the above findings it may be pointed out that floating matter is always carried at or near the surface, rarely reaching to 3 ft. below it, and the toe of a gate of, say 9 ft. high, would always be much more than 3 ft. below the surface The chance of fouling with floating matter is, therefore, remote. Large objects like trees or shrubs with roots, would be most easily arrested by means of bars fixed across the opening on the up-stream side. It should be mentioned also that for river weirs a special design is available, whereby the automatic shutter is held up by a dead weight and chain which are covered up in a masonry chamber.

* Bombay Government Report, No. W. 1—2808, 1905.



THE PROPOSED CHANNEL TUNNEL.
(For description see p. 77.)



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